WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

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The Underground and Surface Water Supplies of Wisconsin

BY

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PREFACE

The investigation which has led to the publication of the following report was started by the United States Geological Survey in 1903. The work was undertaken by Mr. Alfred R. Schultz, under the direction of Mr. M. L. Fuller, at that time Chief of the Eastern Section, Division of Hydrology. The manuscript report of Mr. Schultz, entitled "Underground Waters of the Wisconsin District", describing the area of northern Illinois and the Northern Peninsula of Michigan, as well as of Wisconsin, was completed for publication in 1905. The publication fund of the United States Geological Survey was exhausted at that time and the report was turned over to The Wisconsin Geological and Natural History Survey for publication.

As a part of the manuscript dealt with territory outside of Wisconsin it seemed advisable to alter and amend the work to make it conform to the state boundaries before publishing it as a State Survey report. Unforeseen circumstances arose to delay publication, and in the meantime new facts were obtained in the course of work by the Wisconsin Survey which made it appear advisable to add to the report before publication. This work was assigned to Mr. Weidman of the Wisconsin Survey in 1908, since which time he has devoted such time to this work as was not required by his other duties. He has collected additional data in parts of the state not visited in the original investigation, and has added to the descriptive details of other portions of the State. In revising the descriptive details of localities, the data was rearranged and rewritten into separate county descriptions, as presented in Part II. Additional mineral analyses of Wisconsin water supplies were collected and these, together with those of the original report were correlated with their geologic source and arranged by counties in order to be accessible and more convenient for local use. Mineral analyses of surface waters, as well as additional underground waters, have been compiled. Three of the chapters of the report, namely Chapter IV, "Prospecting for Flowing Wells", Chapter VII, "The Chem-

ical Quality and Factors Affecting the Mineralization of Underground Waters'', and Chapter VIII, ''The Surface Water Supplies and Their Chemical Quality'', were added by Mr. Weidman.

Since the report is made up of important contributions by both, to the knowledge of water supplies it is issued under the joint authorship of Mr. Weidman and Mr. Schultz.

E. A. BIRGE, Director.

THE UNDERGROUND AND SURFACE WATER SUPPLIES OF WISCONSIN.

BY

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Wisconsin Geological and Natural History Survey

AND

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INTRODUCTION.

The investigation of the water resources of Wisconsin has been under way for some time, having been carried on at intervals during the past ten or twelve years. Since the work was started the original plan of the investigation has been altered with reference to the area described, and modified with respect to the various phases of water supplies discussed.

THE WORK OF ALFRED R. SCHULTZ.

During the summer of 1903, A. R. Schultz, was assigned by the United States Geological Survey to the study of the underground waters of Wisconsin, Northern Illinois, and the Northern Peninsula of Michigan, the territory comprised being referred to as the Wisconsin District. The more important parts of the district were visited and examined and the remainder was covered as completely as possible by correspondence.

In 1905 a brief account of the underground water conditions in the Wisconsin District by Mr. Schultz was published.[1] In 1905 the preparation of a report on this district was completed, which was then submitted by the United States Geological Survey to the Wisconsin Geological and Natural History Survey for publication.

The manuscript report of Mr. Schultz consisted of something over 400 pages of typewritten copy and numerous illustrations, with tables

[1] U. S. Geol. Survey, W. S. P. No. 114, p. 233–241.

of well records, and mineral analyses of underground waters. About one-half of this manuscript with the well records and analyses dealt with territory outside of Wisconsin. The following is quoted with but slight change from the Introductory Chapter:

"In the preparation of this report the writer has endeavored to use all the available data, including that derived from other observers, as well as that gathered during the present investigation. A number of records for Illinois have already been collected and published by Mr. Leverett.[1] These records have been used by the writer and compared with the records obtained through correspondence and all available additional data have been added. A large part of the earlier records in Wisconsin have been taken from the "Geology of Wisconsin" particularly Vol. II, by T. C. Chamberlin. The same report has repeatedly been referred to for the geology of the district. The Michigan, Illinois, Iowa, and Minnesota Survey reports have been consulted and the few records embodied in these reports, throwing light upon the condition in the Wisconsin district, have been utilized. A report by Prof. D. W. Mead on "The Hydrology of the Upper Mississippi Valley and Adjacent Territory"[2] was furnished the writer by Prof. Mead and some data not previously obtained were taken from this source.

"From the 12th of May to the 18th of July, 1903, the writer was assisted by Mr. G. W. Crane, who visited a large number of localities in the Green Bay Valley and southward along Lake Michigan as far as Waukegan, Illinois. Mr. Crane obtained much valuable data concerning the distribution of the drift wells, the description of wells from the various horizons west of Green Bay, and the logs of wells which throw considerable light upon the conditions of the St. Peter sandstone over its northward extension. The writer's observation covered the more important parts of the remaining district in Wisconsin, while the outlying sections and those of minor importance were covered by correspondence.

"The writer wishes here to acknowledge his indebtedness to the persons who aided him in the preparation of this report, either directly or by so generously responding to his letters of inquiry, without which much of the material could not here be presented. He is especially indebted to Dr. Alfred C. Lane, State Geologist of Michigan, who by correspondence and published material, has presented valuable information regarding the underground waters in the Northern Peninsula of Michigan. Thanks are also due Mr. Henry Rettinghouse, Superintend-

[1] Seventeenth Ann. Rept., U. S. Geol. Surv., Pt. 2, 1896, pp. 701-842: U. S. Geol. Surv., Mon.. XXXVIII 1899.

[2] Assoc. of Eng. Societies, Jour., Vol. 13, No. 7, 68 pp. 1894.

ent of Bridges and Building for the Chicago North-Western Railroad, for numerous logs of wells sunk by that Company on the Ashland Division, and to Mr. W. G. Kirchoffer, Consulting Engineer of Madison, for many valuable records and suggestions on field observations. (The records and data of Mr. Kirchoffer were published[1] in 1905 and have been freely utilized in the final preparation of this report.)

"The writer should also acknowledge his indebtedness to Prof. T. C. Chamberlin and Dr. W. C. Alden of the United States Geological Survey, for the use of their field notes on southeastern Wisconsin; to Mr. M. O. Leighton for the use of data turned over to him by the Chicago, Milwaukee and St. Paul Railroad; to A. C. Veatch for numerous suggestions; and to Mr. M. L. Fuller for suggestions on field work during the summer months."

The Work of Samuel Weidman.

As the original plan of the work of Mr. Schultz included the investigation of the underground water resources of a large part of Illinois and Michigan, it was necessary, on this account, to alter and amend the work very considerably in preparing it for publication as a report of the Wisconsin Survey. The labor of making the best use of the manuscript of Mr. Schultz, and the task of obtaining additional data to complete the work for publication was undertaken by Mr. Weidman in 1908 and has been carried on by him as the time available from other duties has permitted.

The report, submitted by Mr. Schultz, has served as the principal basis for some of the chapters of the present publication, and has been used verbatim by Mr. Weidman whenever it was convenient to do so. It was found necessary, however, as already stated, not only to deduct the descriptive matter pertaining to Michigan and Illinois, but, also, to collect much additional data, and to greatly add to the descriptive matter of considerable portions of Wisconsin. In revising the descriptive details of localities, these were rearranged and largely rewritten into separate county descriptions. Many additional mineral analyses of Wisconsin water supplies were collected, and these were likewise arranged by counties, in order to be more accessible and more convenient for local use as well as for the reason that such arrangement is more appropriate for scientific discussion and correlation. Mineral analyses of surface waters, as well as of additional underground waters, have been

[1] The Sources of Water Supply in Wisconsin. Bull. Univ. of Wis. No. 106, 1905.

compiled, one of the additional chapters of the work being on surface water supplies of the state.

Besides Chapter VIII, "The Surface Water Supplies and Their Chemical Quality", Chapter IV, "Prospecting for Flowing Wells", and Chapter VII, "The Chemical Quality and Factors Affecting the Mineralization of Underground Water Supplies", were added by Mr. Weidman. He also prepared most of the illustrations. Although the manuscript report submitted by Mr. Schultz contained many illustrations, only 4 of these could be conveniently utilized on account of changes in the scope of the report, these being Plates III and IV and Figures 30 and 57.

Briefly stated, therefore, the original manuscript report of Mr. Schultz has been greatly revised and has been utilized by Mr. Weidman as a basis for a more complete report. Many additional facts have been compiled from both published and unpublished sources, as well as from original investigation, and the various data from all available sources regarding water supplies, artesian conditions and mineral analyses have been classified and correlated in as scientific a manner as possible, with their geologic and geographic environment.

Object of the Investigation.

The need of an investigation of our water supplies is obvious to all, as water is used for many industrial purposes, as well as for drinking and domestic use. The quantity of water available, as well as the quality, are two prime objects that should be kept in mind by those in search of a supply. Local well drillers, while quite fully conversant with local conditions for common farm wells, cannot be expected to know, either the quantity or quality of certain sources of supply, especially of artesian supplies, or the depth at which they can be reached, for the larger use of villages and cities. For obtaining the largest and best supplies for municipal or industrial use there is needed the skillful interpretation of geologic data collected from a considerable area and a general acquaintance of the quantity and quality of the supply likely to be available in the locality.

The detailed descriptions of local geological conditions and of the sources and character of water supplies presented in this work are for the purpose of furnishing to each county and locality the best information and deductions available concerning the water resources in the various localities. For this purpose the general depth of the water-bearing strata in each county is given and illustrated by appropriate diagrams; the character and thickness of each water-bearing formation

is described; the artesian conditions are discussed; and the mineral quality of the water in the various water-bearing formations is indicated. In addition more or less detailed descriptions of well sections and water supplies for each city or village are given as space available appeared to warrant and the data permitted. It should be stated that a large amount of data bearing on the subject of water resources has been compiled from various localities which it appears to be unnecessary to publish. The data, however, have been studied and have been used as a basis upon which generalizations and deductions have been made concerning the local undergound conditions.

The value of this published investigation will depend largely upon its intelligent use by local well drillers, municipal officers, engineers and others in search of water supplies. If it is desirable to obtain additional information concerning certain localities, this information will be furnished by the State Survey from additional data, so far as available.

Geologic Investigation of Wells.

The records and logs of wells in various localities of the state furnish data of the greatest importance to the geologist or engineer in any investigation of local water resources. While the geological structure of the state is relatively simple on account of the fact that the successive strata overlie each other in regular order from the central to the outer portions of the state, like an imbricated pattern, and therefore the general geological relations and general thickness of strata are known in all parts of the state, yet the local conditions, depending upon various factors, are variable to a certain extent; hence it is important to have as complete records of the strata as possible in each locality. While the approximate position and thickness of strata can be inferred from the position of local surrounding outcrops, the local well records are necessarily relied upon to furnish the exact data.

Well Records—The data on which deductions concerning the artesian conditions in various parts of the state are largely or entirely based, have been the records of wells put down in the various artesian districts and localities. A large number of these records are necessarily second hand and many are incapable of verification. In many instances, however, either the owner or the well driller has placed on record much valuable data as to diameters of the bore and casings, fluctuation of water in the tube, depth, discharge and head of water-bearing horizons, and in some instances the driller's log and samples of the drillings have been obtained. It is unfortunate that little or nothing is now known except the present head and discharge of many of the artesian flowing

wells of the state. Even where artesian wells are non-flowing or are now abandoned detailed information of such wells would be valuable for later use in the search of water in the same locality.

Of equal importance with artesian phenomena is the value of accurate data as to the exact source of supply in the investigation of the chemical quality of the water for industrial uses. There are very generally appreciable differences in the mineral content of water from various water-bearing strata, hence it is of much importance to have all the information that is possibly available concerning the source of supply, in order to forecast the probable mineral quality of the supply that is obtainable.

The well driller or the owner should compile and preserve the following data concerning each deep or otherwise important well drilled for a municipality, industrial plant, or other public or private purpose:

1. Ownership and location of well.
2. Location with respect to surface features (in a valley or upon a hill.)
3. Character and thickness of surface formation.
4. Character and thickness of first kind of rock.
5. Character and thickness of each succeeding kind of rock.
6. Total depth of well.
7. Length and diameter of casing.
8. Diameter of well below casing.
9. If an ordinary groundwater well, give depth of water in well.
10. If a non-flowing artesian well give depth or depths at which rise of water was obtained, and height at which water rose in the well, and depth of water in the well.
11. If a flowing artesian well give:—
    a. Depth at which first water rise was obtained and head of same.
    b. Depth of each succeeding rise and head of same.
    c. Artesian head above curb.
    d. Average discharge of well at curb.
    e. Change in head or discharge if any noted.
12. Additional information or remarks.

Samples of Drillings.—A full set of samples of the drillings of all the deep wells of the state should be preserved. The samples can be taken at intervals of preferably 5 or 10 feet and at every change in the strata and never less often than every 20 feet even in the same kind of rock. The drillings should not be washed, but transferred directly from the slush bucket to a clean receptacle, and after drying, preserved in separ-

ate cloth bags or in one to four ounce bottles. When samples are properly taken and labeled at once with the exact depth from which they are drawn they form a very valuable record of the strata penetrated.

Interpretations of Records and Samples.—The rocks penetrated in deep well borings are often difficult to interpret from descriptions given by well drillers. Even a careful examination of well drillings under the microscope by a geologist sometimes does not suffice to determine the exact character of the formation from which such drillings are supposed to have been derived. Various modifications in the character of the formations tend to be misleading in the interpretations of well records, and hence a detailed geological knowledge of the locality and a careful examination of the well drillings, are usually necessary before exact horizons in deep well borings can be definitely determined.

Preservation of Records and Samples.—The State Geological Survey or the Geological Department of the State University will be pleased to receive and preserve all records and logs of wells and the samples of drillings. The drillings and the geological strata penetrated may then be identified, and the samples preserved in uniform receptacles, and all data and samples filed and made readily accessible for present use or future reference. Upon application to this Survey sacks for preserving samples will be sent free of charge.

The carefully made well records and the preservation of samples are not only of the greatest value in acquiring an understanding of the best available underground water resources of various localities in the state, as described in a general report like the following, but the information compiled from these records and inferences based thereon are very often called for and utilized by many municipal authorities, either directly or indirectly, in developing new or additional water supplies.

The authors are indebted to Mr. F. T. Thwaites for the compilation and interpretation of many of the well records presented in this report.

Chemical Investigation of the Water Supplies.

In the investigation of the mineral quality of the underground and surface water supplies no analytical work directly for this report has been undertaken by the State Survey. The mineral analyses compiled, however, appear to be sufficient in number and in their distribution to represent the average mineralization of the water in the various parts of the state. Undoubtedly additional analyses could have been made in certain localities obtained from certain water-bearing horizons that would have thrown much light upon the local mineralization of underground water supplies, but in a general way these additional analyses would not have added appreciably to our general knowledge of the

chemical quality of the water of the various counties and districts of the state.

Additional analyses, however, are very essential in the investigation of the mineral quality of local water supplies in the various water-bearing horizons, where these have not already been made and definitely correlated or where treatment of the water by softening processes is deemed advisable. In this future analytical work, the general conditions and conclusions described in this report concerning the chemical quality should be of much real aid and importance.

Most of the mineral analyses of water of the underground supplies have been made for industrial purposes, mainly in investigating the quality of the water used in railroad locomotives. Many of the analyses of the surface water, mainly the lake waters, have been compiled from reports of the State Geological Survey and of the United States Geological Survey. The various analyses are properly credited to their respective authors in the county tables of mineral analyses, but acknowledgment of generous aid received from various important sources may also appropriatly be given here.

The report contains about 600 analyses of well and spring waters, and over 200 analyses of river and lake waters. Of these about 400 analyses have been furnished by the Chicago, Milwaukee and St. Paul Railroad, mainly through the courtesy of Mr. G. N. Prentiss, Chemist of the Motive Power Department, and about 200 analyses have been furnished by the Chicago and Northwestern Railroad through the courtesy of Mr. G. M. Davidson, Engineer of Tests. The other railroads of the state have furnished copies of incomplete mineral analyses, which have been of value in this investigation, but because of their incompleteness are not included in the tables of mineral analyses. About 40 analyses, many of them being of city water supplies, have been furnished by the Dearborn Drug and Chemical Works, Chicago, and a few by the Milwaukee Industrial Chemical Institute and by the Lasché Institute of Fermentology of Milwaukee. Many of the analyses of inland lakes are compiled from the published work of E. A. Birge, and C. Juday Wis. Survey Bulletin No. 22, and the series of analyses of Wisconsin and Chippewa rivers, and of Lake Superior and Lake Michigan, are taken from the published work of R. B. Dole, U. S. Geol. Survey, Water Supply Paper No. 236. Others to whom special credit should be given for numerous analyses are Professor E. G. Smith of Beloit College, and the late Professor W. W. Daniells of the State University. The authors are indebted to Prof. Richard Fisher for briefly criticising the chapters relating to chemical composition of the waters.

PART I

THE GENERAL CONDITIONS AFFECTING WATER SUPPLIES

Under general conditions affecting the water supplies, a description of the topographic features, climate, rainfall, and geological formations of Wisconsin is given, and the conditions affecting the movement of underground and artesian water, and the flowing artesian wells, and the mineral springs of the state, are described. The general mineral composition and uses of water supplies are explained, and the chemical quality of the underground and surface water supplies and the factors affecting their mineralization are discussed.

The general description of the water supplies of Wisconsin are described in eight chapters, as follows:

Chapter I. Geography and Geology.

Chapter II. Conditions Controlling Underground and Artesian Waters.

Chapter III. The Flowing Artesian Wells of Wisconsin.

Chapter IV. Prospecting for Flowing Wells.

Chapter V. Springs and Mineral Waters.

Chapter VI. The General Composition and Uses of Water Supplies.

Chapter VII. The Chemical Quality and Factors Affecting the Mineralization of the Underground Water Supplies.

Chapter VIII. The Surface Water Supplies and Their Chemical Quality.

CHAPTER I.

GEOGRAPHY AND GEOLOGY.

General Statement.

The value of a sufficient supply of pure wholesome water for drinking purposes, in both city and rural districts, can not be overestimated. Large quantities of water are also used for manufacturing purposes, for fire protection, and for watering stock. It is also used for irrigation and for water power.

The inhabitants of Wisconsin obtain their potable water supplies from underground water, from both shallow and deep artesian wells, and from surface supplies obtained from the rivers and lakes. Probably more than one-half the population mainly in the rural districts is supplied from relatively shallow groundwater wells. Less than one-fourth of the supplies, including both private and public city supplies, is obtained from deep artesian wells. The supply of much more than one-fourth of the population, namely that of the largest cities, is obtained from lakes and rivers.

In the settlement and development of a region there are several stages in the use of the water supplies. In the early days of settlement, almost without exception, spring water or water from streams is used, the first buildings in villages and in the rural districts being located, primarily, with respect to natural sources of water supply. In rural districts this may be the only source for some time to come, but usually in both rural and urban districts resort is soon made to shallow wells. With the increased growth of the city, the supply from shallow wells becomes inadequate, or the water becomes contaminated, and a change to deeper or artesian sources is the next step. Where such a change to deep wells can not be made because of the lack of the artesian supply, the water supply is pumped from streams or lakes and usually is purified by means of a filtering plant.

Private Water Supplies.—In Wisconsin relatively shallow groundwater wells, as a source of water supply, are of much greater importance than all other sources. At present about one-half the population

of the state, mainly in the rural districts, obtains its water from such wells.

As the country has become more thickly settled, the water level in the shallow wells has become permanently lowered, and many of the wells have been made deeper. The yield in many cases does not exceed several barrels per day. The largest drafts made upon the wells in the rural districts are for watering stock. Many of the wells during dry seasons are barely deep enough to supply sufficient drinking water for 20 to 40 head of cattle. In wet seasons, an abundant supply is usually available.

Public Water Supplies.—The most important source of public water supplies in Wisconsin, is the surface water of the lakes and rivers. Water of Lake Michigan is supplied to Milwaukee, Racine, Kenosha and Sheboygan. Other cities of the state, such as Portage, Merrill and Rhinelander get their supply from the Wisconsin river. The next most important source for public use is artesian water obtained from deep wells, as in Madison and Green Bay. Shallow groundwater wells and springs also supply a number of Wisconsin cities. A condensed statement concerning the ownership of public water supplies and the pumpage, pressure, mains, services and meters is given in the tables, pages 134 to 141.

Conditions Controlling Water Supplies.—The water of the rivers, lakes and underground rocks is maintained by the rainfall, which is raised by evaporation from the ocean, lakes, rivers and the surface of the land. The water that falls as rain upon the land is removed from the surface in three principal ways: (1) by evaporation; (2) by run-off in rills and streams as surface drainage; and (3) by absorption into the surface deposits and underlying rocks.

The various natural conditions affecting the amount and character of water supplies, are such geographic features as the drainage and relief, the climate, the vegetation, the soils, and by such geologic features as the character of the superficial deposits, and the underlying rock with respect to their water-bearing capacities.

GEOGRAPHY.

The total land area of Wisconsin is 54,450 square miles. The altitude of the land along a portion of the eastern boundary, the shore of Lake Michigan, is 581 feet, and along the northern boundary on the shore of Lake Superior is 602 feet. The altitude of the boundary along the Mississippi river from Prescott to Dubuque ranges from 667 at Prescott to 595 feet at the southwest corner of the state, opposite Dubuque. From these lowest altitudes about the boundaries of the state, the land rises to about 1,000 to 1,200 feet in the southern half of the state, and to about 1,500 to 1,800 feet in the northern half of the state.

TOPOGRAPHY.

Dominant Topographic Features.—The dominant topographic feature of Wisconsin consists of a broad arched dome with its highest point in the northern half, from which the surface slopes downward in nearly all directions towards the borders of the state. The principal slopes are northward towards Lake Superor, eastward and southeastward towards Lake Michigan, and westward and southward to the Mississippi river.

The slope to the north is relatively short and steep as compared with the southward slope, the two slopes intersecting along an irregular east-west dividing ridge which extends across northern Wisconsin from Minnesota into the Upper Peninsula of Michigan, the divide being located about twenty-five miles south of Lake Superior. Northern Wisconsin is a region of crystalline rocks nearly 20,000 square miles in area, and apparently marks the position of an early uplift, which gave rise to what has often been called the "Isle of Wisconsin." To the north, the surface declines from an elevation of 1,700 or 1,800 feet, along the divide, down to 602 feet, along the Lake Superior shore.

The southward slope contains a broad, low swell extending south through the middle of Wisconsin which is primarily due to a broad arching of the rocks. This swell, which forms the divide between the Mississippi and Green Bay drainage, is best developed in the vicinity of the northern crystalline area; it gradually becomes less conspicuous southward and finally dies out in northern Illinois, at an elevation of 600 to 700 feet, where the rivers cut directly across it on their way to the Mississippi.

In central Wisconsin, the low north-south swell is broken by other minor elevations, one of the most important forming the watershed of the Wisconsin, Fox, and Rock river drainage basins. Throughout Wisconsin, the rock structure, the position of the strata, controls the larger drainage systems, and determines, to a considerable extent the movement of the underground waters.

Minor Topographic Features.—The minor features of topography, or such as are represented by the ordinary hills and valleys, are due largely to the modification by stream erosion of the broader topographic features just described. The picturesque deep narrow valleys, and the massive battlements of rock rising 200 to 600 feet along the Mississippi River, are striking illustrations of the work of weathering and stream erosion. No less notable are the mounds of southwestern Wisconsin which are remnants of formations which at one time covered the entire area, but which have been removed, in large part, by stream action. These mounds rise abruptly from 100 to 600 feet above the surrounding uplands. The height of Blue Mound is 1,729 feet, while the elevation of the general upland in the vicinity is but 950 to 1,150 feet. Somewhat analogous topography may be seen about Camp Douglas, where the isolated mounds of the Potsdam sandstone rise 150 to 200 feet above an almost level valley bottom plain. The Baraboo, Barron, Chippewa and Wausau quartzite areas, likewise, give rise to hills rising high above the surrounding plain. Similar knobs of granitic rocks are scattered through the Fox River basin. In the northern part of the state, the Penokee-Gogebic iron range possesses a rugged topography, while in northwestern Wisconsin, the Keweenanwan trap rocks form a broad ridge rising 100 to 300 feet above the adjoining plain.

Glacial Features.—The minor features of topography thus far considered resulted largely from stream erosion in pre-glacial and inter-glacial times. Other minor topographic features, over large portions of the state, outside the driftless area, have resulted in a great measure from the action of the several ice sheets whose deposits generally completely covered the pre-glacial features, including many minor river valleys and basins. Well records, for example, in southern Wisconsin have brought to light many buried valleys which reach a maximum depth of 300 to 400 feet.

The glacial features of topography are quite unlike those developed by normal stream erosion. The land forms made by the glaciers consist of low rolling hills of loose drift associated with numerous small lakes and swamps. The topography of the glacial moraines is more rugged and is characterized by irregular knolls and kettles. The glacial

ridges generally rise from a few feet up to 100 feet above the adjacent lowlands, and occur in belts or zones whose widths vary from a few miles up to 20 miles.

HYDROGRAPHY.

The principal river systems of the state are the Wisconsin river, Chippewa river, St. Croix river, Rock river, Fox river, Menominee river, Peshtigo river, Oconto river, Black river, and the rivers flowing into Lake Superior.

Wisconsin River System.—Because of its length and its great drainage area, the Wisconsin river is preeminently the main river of the state. Its extreme source is found in Lac Vieux Desert, a body of water of about 10 square miles in extent, on the boundary of Michigan and Wisconsin, at about 1,650 feet above sea level. The drainage basin of the Wisconsin system includes 12,280 square miles, with an average width of 50 miles, and a length of about 225 miles. The principal tributaries of the Wisconsin river, beginning at the north, are the Pelican river, Tomahawk river, Prairie river, Rib river, Eau Claire river, Big Eau Plaine River, Little Eau Plaine river, Yellow river, Lemonweir river, Baraboo river and the Kickapoo river.

Chippewa River System.—The Chippewa drainage system has its source in over 100 lakes, large and small, with many connecting swamps, near the Michigan boundary, and only 20 miles from Lake Superior. The drainage area has a length of 180 miles, a maximum width of 90 miles, and an average width of nearly 60 miles. The total area drained by the river is 9,573 square miles, of which about 6,000 square miles includes the thinly settled region of Wisconsin. The headwaters of the system rise at an elevation of a little over 1,600 feet above the sea, and it empties into the Mississippi river at an altitude of 664 feet. The principal tributaries of the Chippewa are the Flambeau river, Jump river, and the Yellow river on the east, and the Red Cedar on the west.

Fox River System.—The Fox river system, the main drainage line in the eastern part of the state, has a drainage area of 6,449 square miles. The average flow is calculated as 3,007 second-feet, at Rapid Croche dam. The Lower Fox, below Lake Winnebago, has a rapid fall of 170 feet in 28 miles. The Upper Fox, that portion above Lake Winnebago, descends only 35.3 feet in the 106.8 miles between Portage and Lake Winnebago, an average fall of less than 0.5 feet to the mile. The Wolf river, the principal tributary of the Fox, is over 160 miles long, and has a fall from 1,562 feet at its source to 746 feet at lake Poygan. Between Shawano and Winneconne, a distance of 80 miles, the

river has a descent of only about 42 feet, less than 0.5 foot per mile. In this portion of the river, the banks are low, and in high water the surrounding flats are covered for several miles in width.

Menominee River System.—The Menominee drainage basin is narrow in its lower portion, but widens as the stream is ascended, the river receiving many important branches near its source. Its total drainage area is about 4,000 square miles, of which only 1,450 square miles is in Wisconsin.

Peshtigo River System.—The drainage area of the Peshtigo river includes 1,123 square miles, and has an extreme length of 80 miles, with an average width of only 14 miles. The upper two-thirds of its length is in the Pre-Cambrian, while in the lower one-third it crosses successively the Potsdam sandstone and the Lower Magnesian and the Trenton limestones. At Crandon, the Peshtigo river has an elevation of 1,620 feet above the sea, and has an average gradient of 11 feet per mile in it descends 945 feet to Green Bay.

Oconto River System.—The Oconto river rises in a number of small lakes and swamps at an elevation of 1,530 feet above the sea. It has a drainage area of about 1,100 square miles. In its length of 87 miles it descends 945 feet.

Black River System.—The Black river drainage area is hemmed in by the Chippewa river on the west and the Wisconsin river on the east, and is restricted to a long and narrow watershed of about 2,270 square miles, with an average width of only 20 miles. The Black river rises at an elevation of about 1,400 feet above sea level, and after a sinuous course of 140 miles, joins the Mississippi river at La Crosse, with a descent in this distance of 772 feet.

The St. Croix River System.—The St. Croix river rises at an elevation of 1,010 feet in the St. Croix lake, on the Lake Superior divide, only 20 miles from Lake Superior. The total drainage area comprises 7,576 square miles, the greater part of which is in Wisconsin. The Wisconsin portion of the drainage basin has a width of 50 miles on its northern margin and extends southwesterly, to the Mississippi river a distance of about 150 miles. The principal tributaries of the St. Croix, in Wisconsin, are the Willow river, Apple river, Yellow river, Nemakagon river, and the Eau Claire river.

Rock River System.—The Rock river occupies the southern half of a depression that extends from Green Bay and Lake Winnebago southwest to the southern end of the state. The total drainage area of the river, above the state line, is approximately 3,500 square miles, not including the valley of the Sugar river and Pecatonica river. The Rock river valley has an extreme length of 85 miles and a width of 65

miles. The headwaters of the Rock rise at an elevation of about 950 feet. The average fall of the river, between Horicon and the state line, is only a little over one foot to the mile. The principal tributaries of the Rock river are the Bark river, Crawfish river, Yahara river, and the Sugar and Pecatonica rivers, the latter two of which flow into the Rock river below the state line.

Lake Michigan Drainage.—The principal rivers flowing into Lake Michigan are the Menominee river and the Milwaukee river, flowing into Lake Michigan at Milwaukee, the Sheboygan river, flowing into the lake at Sheboygan, and the Manitowoc river, entering at Manitowoc.

Lake Superior Drainage.—The principal rivers flowing into Lake Superior are the Montreal river, Bad river, White river, Iron river, Brule river, Amnicon river, and the Nemadji river.

Great Lakes.—Two of the Great Lakes, Michigan and Superior, lie respectively on the eastern and northern boundaries of the state. These lakes are so large that they materially effect the climatic conditions, not only greatly moderating the climate within 10 or 15 miles of the lake, but also directly and indirectly influencing weather conditions over much larger portions of the state.

Inland Lakes.—Besides the two Great Lakes, Michigan and Superior, that lie respectively on the eastern and northern boundaries, there are over a thousand inland lakes in Wisconsin, that profoundly affect the the general water supply conditions of the state. In most instances these lakes occupy basins left in the irregular surface of the glacial deposits.

Lake Winnebago, the largest of the inland lakes, lies in the Fox river valley, and has an area of about 200 square miles. Other important lakes in the Fox river system are Lake Big Buttes des Morts, Lake Puckaway, Green Lake, and Rush Lake; and on the Wolf river are Lake Poygan and Lake Shawano. Lake Noque Bay is an important lake drained by one of the tributaries of the Menominee river.

In the Rock river valley are Beaver Lake, Lake Koshkonong, Lake Mendota, and Lake Monona.

At the headwaters of the Wisconsin river are many lakes, chief among which may be mentioned Lac Vieux Desert, Pelican Lake, Tomahawk Lake, Fence Lake, Plum Lake, and Trout Lake.

At the source of the Chippewa river system are the numerous large lakes at the head of the Flambeau river in Iron and Vilas counties, Lac Court O'Reille on the Chippewa proper, and such large lakes on the Red Cedar as Lake Chetek, Red Cedar Lake, Long Lake, and Bear Lake.

The St. Croix river system drains many lakes in Northwestern Wisconsin, a few of which are Lake Nemakagon, Lake Owen, Upper St. Croix Lake, Clam Lake, Yellow Lake, Spooner Lake, Summit Lake, Bone Lake, and Sucker Lake.

Lake Pepin, an expansion of the Mississippi river, and Lake St. Croix an expansion of the St. Croix river at Hudson are important lakes on the western border of the state. For a condensed statement concerning the areas and depths of the inland lakes, see the tables, pages 208–209.

Marshes.—Much the same agencies that produced most of the inland lakes caused the extensive marshy and swampy tracts that occur in the eastern and northern parts of the state. In many counties there is less than one per cent marsh land, but in one or two counties 30 to 40 per cent is marsh and swamp land. Probably 10 or 15 per cent of the entire state should be classed as wet marsh land. Much has already been done to reclaim these wet lands, and net works of drainage ditches have so reduced the water level in some of these that they are now annually plowed. Only a small percentage of the marsh lands, however, have been drained.

RAINFALL.

Intimately associated with the geological outcrop, as a factor in determining the amount of water supplies, is the amount of precipitation, or rainfall, that the area annually receives, and its distribution through the various seasons of the year. If the precipitation is uniformly distributed throughout the year a much larger proportion will be absorbed than if it all falls within a few months. In the latter case the per cent of run-off will be greatly increased, and the per cent absorbed as phreatic water will be considerably less. The difference between run-off and phreatic water is still greater if most of the precipitation occurs during the winter season when the ground is frozen, as the amount of water that the strata or outcrop may then take in, is considerably reduced. For these and similar reasons, the essential factor is not the total precipitation alone, but its seasonal distribution.

The annual precipitation in Wisconsin usually ranges between 25 and 35 inches, the average being not far above 31 inches. In the following table (Table 1) is shown the mean monthly and mean annual precipitation at 12 Weather Bureau stations located in various parts of the State

TABLE I—*Monthly and annual precipitation in inches for various Wisconsin stations.*

Station.	Elevation.	Period of observation.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
	Feet.	Ye'rs.													
Ashland........	647	19	1.14	1.23	1.53	2.11	3.30	3.43	4.07	3.14	3.13	2.84	1.53	1.21	28.66
Osceola.........	806	19	1.00	0.92	1.90	2.33	4.27	4.75	4.12	3.28	4.05	2.95	1.39	1.17	32.13
Eau Claire......	800	19	1.00	1.28	2.04	2.58	4.37	4.66	3.47	3.26	3.93	3.22	1.67	1.48	32.96
Medford........	1420	20	0.96	1.09	1.45	2.26	4.26	5.10	4.09	3.52	4.05	3.41	1.57	1.28	33.05
Koepenick......	1683	19	1.35	1.28	1.86	2.71	3.62	3.96	3.84	3.41	4.21	3.17	1.98	1.26	32.65
Florence........	1293	18	1.08	1.39	2.05	2.44	3.76	3.53	4.10	3.20	3.27	2.60	2.11	1.54	31.07
La Crosse.......	681	37	1.12	1.06	1.61	2.39	3.75	4.38	3.93	3.66	4.08	2.39	1.59	1.35	31.31
Lancaster.......	1070	18	1.04	1.13	1.75	2.95	4.35	4.15	4.11	2.70	2.31	2.06	1.76	1.28	30.59
Madison........	974	31	1.63	1.50	2.08	2.54	3.66	4.01	3.80	3.15	3.08	2.32	1.76	1.72	31.25
Beloit...........	750	34	1.88	1.71	2.21	2.77	3.56	4.05	3.65	3.61	3.39	2.08	1.91	1.89	32.71
Manitowoc......	616	37	1.70	1.51	2.13	2.49	2.76	3.47	3.57	2.99	2.11	2.54	2.08	1.82	30.18
Milwaukee......	681	29	2.08	1.86	2.60	2.75	3.39	3.62	3.10	2.84	2.96	2.15	1.93	1.90	31.19
Means..........	......	......	1.33	1.33	1.93	2.52	3.75	4.09	3.82	3.23	3.38	2.73	1.77	1.49	31.48

From this table, it may be seen, that for the six months, April to September inclusive, a little over 65 per cent of the annual fall is registered, while for the six months of winter, less than 35 per cent of the precipitation is registered. The amount falling in December, January and February is less than 14 per cent of the annual. A considerable part of the precipitation of central and northern Wisconsin falls in the form of snow. The amount of water falling annually as snow generally varies between two and ten inches, the average for northern Wisconsin being six or seven inches, and for southern Wisconsin two or three inches.

The extreme conditions for precipitation as above stated are important factors to take into consideration in studying the various influences affecting water supplies. At Madison, in the last forty-five years, the extreme variations in the total annual rainfall have been, from a minimum of 13 inches to a maximum of 52 inches, the minimum being only 25 per cent of the maximum. (See Fig. 1.)

As a general rule, however, the minimum rainfall is about 50 per cent of the maximum in the upper Mississippi valley,

TEMPERATURE.

The temperature conditions that prevail in any region, are closely associated with and intimately related to precipitation, as influences on the amount of water absorbed by strata. The mean annual temperature ranges from about 47° F., in southern Wisconsin, to about 40° F.,

in the northern part, along the divide south of Lake Superior. The mean temperature for the winter months is about 12° to 30° F., and for the summer months, between 60° and 70° F. The extreme temperatures range from -30° to -50° in winter to over 100°F., in summer.

Temperature has its most marked effect on the relation of precipitation to run-off. This is especially true in the freezing weather of the winter months. Ordinary ground, even though pervious and unsaturated, may be rendered impervious by surface freezing and thus permit a rapid flow of the rainfall into streams. On the other hand, in

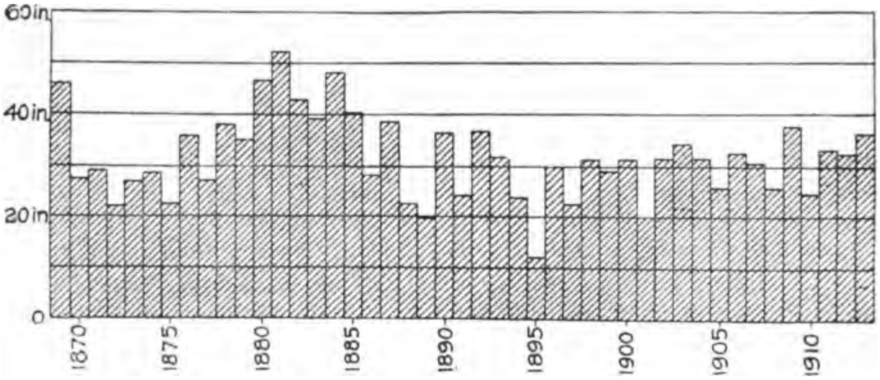

Fig. 1.—Diagram illustrating the fluctuation of the annual rainfall in inches at Madison, Wis., from 1869 to 1913.

regions of heavy snow fall, as in northern Wisconsin, the soil remains unfrozen during winter and the conditions of absorption and stream flow are rendered more uniform.

EVAPORATION.

The evaporation of the rainfall is more important, though far less conspicuous, than other methods of removal. The amount evaported depends upon climatic conditions, mainly temperature and dryness of the air, amount of vegetation and water surface, and commonly amounts to one-half, or more, of the total water falling as rain in a locality or district.

RUN-OFF.

The amount of rain that is removed as run-off, or surface drainage, is partly dependent on evaporation and partly on the nature of the

rock material and the slope of the land on which the rain falls. The percentage of run-off to rainfall in Wisconsin as stated by Prof. D. W. Mead[1] is sometimes as low as 16 per cent and sometimes as high as 70 per cent. Prof. Mead states that, as a general rule, the rivers of Wisconsin may be divided into two groups—one group, which includes the Menominee, Peshtigo, Wisconsin, Chippewa and Flambeau (rivers which rise in the granitic highlands of the state), average about 55 per cent run-off; the other group, which includes the Rock, and Fox, (rivers which originate on territory underlaid by later geological deposits) averages about 27 per cent run-off. (See Table 2.) The departure in each group from the average conditions may be regarded as the measure of the effect of other factors besides quantity of precipitation in affecting run-off.

TABLE 2.—*Showing mean annual rainfall and runoff, and the percentage of runoff.*

River.	Years.	Mean Rainfall Inches.	Mean Runoff Inches.	Runoff in per Cent of Rainfall.
Wisconsin	1903—1908	33.71	21.82	64.8
Peshtigo	1907—1908	24.96	11.02	43.2
Chippewa	1904—1908	32.54	16.16	49.6
Flambeau	1903—1904	39.29	19.07	48.5
St. Croix	1902—1909	31.28	9.51	30.4
Menominee	1903—1907	32.83	17.54	53.4
Rock	1904—1908	32.20	6.84	21.2
Fox	1897—1906	32.58	7.97	24.5

The run-off in percentage of rainfall of the Chippewa river and the Fox river is shown in the following table:

TABLE 3.—*Annual relation of rainfall and runoff on the Fox River.*

Year.	Rainfall Inches.	Runoff Inches.	Runoff in Per Cent of Rainfall.
1897	26.08	6.04	23.2
1898	26.15	5.47	20.9
1899	29.74	6.26	21.1
1900	36.76	6.70	18.2
1901	30.27	8.07	26.7
1902	30.50	6.66	21.8
1903	38.75	9.00	24.1
1904	25.31	9.27	26.2
1905	36.87	11.97	32.3
1906	36.36	10.81	29.8
1907	32.62	10.48	32.1

[1] Flow of Streams and Factors that modify it in Wisconsin, Bulletin, University of Wis., No. 425., p. 125.

TABLE 3. *Annual relation of rainfall and runoff on the Chippewa River.*—Continued

Year.	Rainfall Inches	Runoff Inches	Runoff in Per Cent of Rainfall
1903	37.97	21.07	55.6
1904	35.86	16.83	47.0
1905	36.95	17.62	47.7
1906	31.80	16.55	52.0
1907	23.36	14.27	61.0
1908	29.31	10.63	36.3

ABSORPTION.

A part of the rainfall sinks into the ground, and becames groundwater. The pores and fissures in the surface deposits and through the underlying rocks become saturated below a certain level, known as the groundwater level, or the groundwater table. The groundwater, after sinking below the surface, mainly moves downward to the groundwater level, below which all the pores in the rocks are filled. After it reaches the groundwater level, it flows mainly in a lateral direction in conformity with the dip of the rocks and the general trend of the surface drainage.

The amount of rain absorbed by the soil and rock depends upon the porous character of the soil and of the underlying rock formation, and varies considerably in different parts of the state and within different drainage systems.

The mechanical analyses of soils on page 23 illustrates the size of grain of the soil from which the size of pore space and capacity of the flow of water through such soils can be readily determined. The sand or sandy loam soils, consisting largely of coarse and fine sand, with relatively large pore-space, absorb the rainfall much more freely than the clay loams and clay soils, which consist largely of fine silt and clay particles, with only minute pore spaces between the soil particles.

AGRICULTURAL AND FOREST CONDITIONS.

Soils.—The soils of Wisconsin vary from light sandy soils to heavy clay soils. Most of the farm lands are characterized, however, by medium phases of sandy loams and clay loams. The heaviest clay soils are the red lacustrine clays that lie along the shores of Lake Superior, Lake Michigan, and Green Bay, and up the valleys of the Fox river, as well as to a limited extent over the limestone uplands in the eastern part of the state. The sandy loam soils occur over a large part of northern and central Wisconsin.

The loams that predominate over most parts of the state are rich.

fertile soils and are mainly of glacial or loessial origin. The soils in general are fertile, and are not subjected to conditions of erosion, because of the favorable conditions of gentle slope and the general open physical texture of the soil.

The following mechanical analyses of various types of soils, made by the U. S. Bureau of Soils, are compiled to show the approximate range in physical texture of the various common soils in the state.

TABLE 4.—*Mechanical analyses of typical soils of Wisconsin.*

Name of Soil	General location in Wisconsin	Geological character	Fine gravel 2 to 1 mm.	Coarse sand 1 to 0.5 mm.	Medium sand 0.5 to 0.25 mm.	Fine sand 0.25 to 0.1 mm.	Very fine sand 0.1 to 0.05 mm.	Silt 0.05 to 0.005 mm.	Clay 0.005 0 mm.
			Pr.ct	Pr.ct	Pr.ct	Pr.ct	Pr.ct	Pr.ct	Pr.ct
Plainfield sand...	Central and northern.	Alluvial........	0.5	17.8	30.9	33.9	5.8	6.5	4.5
Plainfield sandy loam.	Central and northern.	Alluvial........	0.1	25.5	23.6	16.5	2.0	22.6	9.1
Boone fine sandy loam.	Western and southern.	Residual on sand stone.	0.2	5.9	13.5	54.9	5.8	14.7	5.1
Chelsea (Coloma) loam.	Northern........	Granitic glaci'l drift.	0.1	5.7	4.0	4.0	19.4	53.6	12.8
Colby silt loam...	Northern........	Granitic glaci'l drift.	0.1	3.2	4.0	3.6	12.6	61.9	13.6
Knox silt loam...	Western and southern......	Loess..........	0.1	0.6	0.5	1.2	5.3	80.8	11.6
Miami fine sandy loam.	Eastern and southern.	Limestone glacial drift.	0.9	5.9	9.4	24.6	18.5	33.1	7.4
Miami clay loam.	Eastern and southern.	Limestone glacial drift.	0.3	4.0	4.0	11.5	12.4	43.2	23.2
Superior clay.....	Adjacent to Great Lakes.	Lacustrine.....	0.2	1.1	1.5	5.4	5.3	28.6	58.2

Besides these soils there are muck and peat soils, occupying bottom lands and marshes. Muck and peat consists of much organic matter, in the form of partially decayed vegetation, with which is mixed a variable amount of sand, silt and clay.

The capacity of the soils to absorb and transmit water, depends directly upon the size and amount of the pore spaces of the soils, as determined by the size of the grains. The coarse sand soils absorb and transmit water much more rapidly than the fine clay soils. However, the fine clay soils generally possess a larger total pore space than the sand soils and therefore are capable of holding a larger amount of water. Most of the rain that falls upon sandy soils, whether hilly or level, is immediately absorbed, readily transmitted downward to the water level, and thence moves off laterally and seeps out of the ground along the banks of rivers and streams and along the borders of marshes and lakes. Most of the rain, however, that falls on the clay soils, especially if the clay lies on slopes and the rains are heavy, can be absorbed

only slowly, and is removed as surface run-off, and thus, almost immediately, reaches the streams and rivers.

Vegetation.—The native vegetation, originally developed over most parts of the state, consisted of mixed hardwoods and pine forests in the central and northern part, and a somewhat lighter growth of hardwoods in the southern part. Light forest growth, so-called "prairies," occurred in the southern and central counties only to a limited extent.

Agriculture.—The principal agricultural industries are grain raising and dairyng. Oats, barley, rye, and wheat are the principal small grains. Corn is raised, mainly, only in the southern and western parts of the state. Dairying and stock raising are important industries over the entire state. Such special crops as tobacco, potatoes, sugar beets, and peas are also very important crops in certain parts of the state.

The daily consumption of water by different crops at the average maximum development during the growing season is shown by the following:

Amount of Water Daily Required for Different Crops.

Meadow grass	0.122 inches of water.
Oats	0.140 inches of water.
Corn	0.140 inches of water.

There appears to be no close agreement in statements regarding the transpiration of forests. Some statements are to the effect that trees consume much more water than agricultural crops, and others that trees consume only from 50 to 100 per cent that of crops.

POPULATION.

The population of Wisconsin, as determined by the U. S. Census in 1910, was 2,333,920, an average of about 43 inhabitants to the square mile. The average distribution of the population, however, is irregular.

In Sawyer county, settlement is least dense, there being but 4.6 people to the square mile, while in Milwaukee county the average is 1,856 to the square mile. The high average in the latter county is due, of course, to the large city of Milwaukee, which has a population of 373,857 in 1910.

The population throughout the well settled counties, in the southern half of the state, is rather evenly distributed, and is approximately 60 people to the square mile.

GEOLOGY.

The indurated or hard rock formations of Wisconsin range in age from the Pre-Cambrian to the Devonian. The formations between the Devonian and the Pleistocene, or Glacial, are not represented, although certain high-level gravels have been interpreted as possibly of Tertiary age. The Pleistocene, or Glacial period, however, is represented over most of the state by a superficial mantle of glacial drift, except in the driftless area of about 10,000 square miles, located in the central and southwestern parts of the state.

OUTLINE OF THE GEOLOGIC HISTORY.

The geologic history of Wisconsin, represented by the rock formations, falls into three great periods which are widely separated from one another. The first, or earliest period, is the Pre-Cambrian; the second, is the Paleozoic; and the third, is the Pleistocene, or Glacial. The various geological formations of Wisconsin, and their relative position in the complete geological series, is shown in the following table, Plate II.

The earliest, or Pre-Cambrian period, or era, is the oldest period recognized in geology, and the various formations deposited in this period, represent portions of the oldest land areas in existence. The formations are both sedimentary and igneous in origin. The sedimentary formations, now greatly metamorphosed, were originally deposited as sandstones (now metamorphosed to quartzite), clays (now metamorphosed to shales and slates), limestones (now metamorphosed to marble), and iron deposits (now metamorphosed to iron ore formations). The various igneous formations are such rocks as granite, trap, and porphyry, of both plutonic and volcanic origin. (Near the close of the Pre-Cambrian, during the long period of the Keweenawan, extensive deposits of probable glacial drift and other land deposits were laid down in close association with volcanic extrusions.) The various Pre-Cambrian formations are themselves widely separated in age and are divided into distinct series or groups, such as the Kewatin, Laurentian, and the two or three series of the Huronian, and the Keweenawan.

The Pre-Cambrian was characterized by such activities as the deposition of sedimentary rocks, the intrusion of volcanic rock, and the upheaval and folding of the strata into mountain ranges.

Before the beginning of the Paleozic age, a long period prevailed, oc-

cupied mainly by sub-aerial erosion; and, as a result, the Pre-Cambrian land was reduced by erosion from a mountainous region to one of comparatively gentle slope (a peneplain of erosion). In the general base-leveling of the Pre-Cambrian, only the hardest and most resistant formations were left as remnants projecting above the plain. These projections (Monadnocks) of the Pre-Cambrian are characteristic features of Wisconsin topography, and are illustrated by such well known examples as the Baraboo Bluffs, the Rib Hill and associated group of quartzite mounds in Marathon and Wood counties, Flambeau Ridge, the Penokee Range, and the various mounds of granite and porphyry in the Fox river valley.

After the Pre-Cambrian had been base-leveled, the waters of the early Paleozoic era encroached upon the land and approximately horizontal beds of sandstone and limestone were deposited. The earliest Paleozoic formation (excluding certain beds of sandstone which are grouped with the Keweenawan) is the Upper Cambrian (Potsdam) sandstone. The deposition of the Upper Cambrian was followed by the successive depositions of the Oneota and Shakopee (Lower Magnesian) limestone, the St. Peter sandstone, the Galena-Platteville limestone, the Cincinnati shale, the Niagara limestone, and some Devonian shale and limestone. Most if not all of these formations are marine deposits and contain marine fossils.

It is probable that some of the earlier formations, such as the Upper Cambrian (Potsdam), may have extended over the entire area of the Pre-Cambrian; but if so, they were entirely removed from it in northern Wisconsin. The later formations (see the geologic map, Plate I), such as the Niagara limestone and the Cincinnati shale, occur only in the eastern part of the state and in occasional mounds in the southwestern part.

The later part of the Paleozoic era, the whole of the Mesozoic era, and most of the Cenozoic era are not represented by geologic formations in Wisconsin. There are no records, therefore, of the geologic history of these periods in the state, the time being apparently represented by sub-aerial erosion.

The Quaternary, or Pleistocene period, the latest of the Cenozoic era is well represented in Wisconsin by extensive deposits of glacial drift, alluvial deposits, and loess. These deposits overlie the uneven and deeply eroded surface of the older indurated formations, and represent the activities of several distinct and separate invasions of continental ice sheets, the extensive deposition by water of alluvial and lacustrine formations in the valleys and lowlands, and the deposits of loess made

by the wind, the latter being confined to the western part of the state, in the driftless and in the old drift regions.

THE PRE-CAMBRIAN (OTHER THAN KEWEENAWAN).

The rock formations of the Pre-Cambrian age occur at the surface, mainly, in the north central and the northern parts of the state. In other parts of the state, the Pre-Cambrian underlies the Paleozoic sandstones and limestones. Isolated outliers of the Pre-Cambrian also are exposed within the area of the Paleozoic, in the southern part of the state, as illustrated by the Huronian quartzites of the Baraboo Bluffs and the granite and rhyolite knobs of the Fox river valley.

The Pre-Cambrian formations consist principally of crystalline or igneous rocks, and highly metamorphosed shales, sandstones and limestones, such as slates, quartzites and marbles. The Lake Superior and Baraboo iron ores, and the copper-bearing rocks are Pre-Cambrian formations. These igneous and metamorphosed rocks, as above stated, have been folded in an intricate manner by mountain making forces.

RELATIONS OF UNDERGROUND WATER TO THE PRE-CAMBRIAN.

While the Pre-Cambrian formations differ in character, their influence is much the same on groundwater conditions. Most of these formations are very fine-grained and close textured, so that very little water percolates through the rocks. Continuous crevices and channels are abundant, usually, only at the surface. As a general rule, no large amount of water, such as amounts needed for villages or cities, can be obtained from this source. In very exceptional cases, however, considerable water may be obtained, and in one or two instances, artesian flows are known to occur in the Pre-Cambrian.

Aside from furnishing a sufficient supply for domestic use on the farms in the northern part of the state where these formations constitute the surface rocks, the Pre-Cambrian crystalline formations exert an important influence on the underground water supply, as the relatively impervious basement controlling the abundant artesian flows in the southeastern, southern, and the southwestern parts of the state. In in other words, the hard fine-grained Pre-Cambrian rocks, which are of minor importance when considered as aquifers, or water-bearing formations, serve admirably as impervious basements for the higher water horizons.

As the Pre-Cambrian, lying deeply buried below the surface in the eastern, southern and southwestern parts of the state, limits the depth

of the water-bearing horizons in those parts of the state, it is important to know the approximate depth of the Pre-Cambrian impervious basement in those regions. As a general rule, the greater the distance of any locality from the area of outcropping Pre-Cambrian of northern Wisconsin, the greater is the depth of the Pre-Cambrian below the surface. The exceptions to this rule are the uneven surface features of the Pre-Cambrian floor which may be caused by undulations in this floor by folding, after the overlying formations were deposited upon it, or to the unevenness in the surface of the floor due to unequal erosion, before the overlying formations were deposited upon it.

On the general geological map of the state, Plate I, is shown the approximate elevation of the Pre-Cambrian above or below sea level, represented by brown lines with the elevation indicated. In order to ascertain the approximate thickness of the water-bearing strata, in any locality or county, a comparative study should be made of the map with the general elevation of the land surface as described under the surface features of each county, and by comparison also with the geologic cross sections for each county. The approximate elevations of the Pre-Cambrian, where deeply overlain by later strata, has been calculated from a study of many deep well records and from general knowledge of the thickness of the overlying strata at the outcrop. In the following table (Table 6), is shown the exact elevations of the Pre-Cambrian in various cities of the state, as determined by deep wells drilled down to the Pre-Cambrian:

TABLE 6.—*Table showing elevation of the Pre-Cambrian in deep wells.*

Eastern Wisconsin.	Depth below Surface, in feet.	Elevation above (+) or below (—) Sea Level, in feet.
Marinette	917	326—
Green Bay	911	311—
Oshkosh	680	75+
Fond du Lac	1,060	300—
Mount Calvary	1,176	116—
Two Rivers	1,800	1,199—
Milwaukee	At least 2,100	At least 1,430—
Southern Wisconsin.		
Portage	530	288+
Madison	750	100+
Watertown	1,085	262—
Janesville	1,087	313—
East Troy	1,725	865—

Western Wisconsin.

Durand	400	320+
Hudson[1]	375	300+
Hastings, Minn.[1]	820	110—
La Crosse	524	128+
Richland Center	665	71+
Boscobel	965	275—
Cassville	1,102	460—
Platteville	1,718	618—

[1] The Upper Cambrian at Hudson and Hastings probably rests on Keweenawan sandstone and shale.

KEWEENAWAN SYSTEM

The rocks described as Keweenawan in northern Wisconsin appear to be referable to three divisions or groups. (1) Lower Keweenawan, consisting mainly of conglomerate and quartzitic sandstone or shale, (2) Middle Keweenawan, consisting of diabase and gabbro in the form of trap or volcanic flows, interstratified with beds of conglomerate, (3) Upper Keweenawan, consisting of conglomerate at the base overlain by red sandstone and shale, known as the Lake Superior sandstone. On the geological map of the state, Plate I, the Keweenawan trap (2), and the Lake Superior sandstone (3) are each shown as separate formations. The Lower Keweenawan conglomerate and quartzite (1) are shown on the map with the Huronian quartzite, as final conclusions concerning correlation of certain quartzite areas, probably Lower Keweenawan, such as the Barron Quartzite, have not been reached.

Relation of underground water to the Keweenawan rocks.—The character of the Keweenawan formation with respect to groundwater conditions is very similar to that of the Huronian formation. This is especially true of the ridges of Keweenawan trap rocks which appear at the surface or immediately underlie the drift in portions of Polk, Burnett, Douglas, Washburn, Bayfield, Ashland and Iron counties.

The Lake Superior sandstone formation lying adjacent to Lake Superior, mainly in Douglas and Bayfield counties, contain numerous beds of shale, and the formations as a whole is relatively impervious. It is usually a firm and well cemented rock, colored red or brown by iron oxide. While this formation attains a thickness of several thousand feet it is unimportant as a source of water supply.

While sufficient water for farm use can usually be obtained in this formation, the drift overlying the sandstone is very generally a much better source of water supply. Many of the deep wells that penetrate the sandstone in Ashland and Superior contain highly mineralized or brackish water and hence deep wells in this formation are generally objectionable as a source of water supply. However, wells that reach only

a few hundred feet into the sandstone, very generally, obtain good fresh water of either low or moderate mineral content.

THE UPPER CAMBRIAN (POTSDAM) SANDSTONE

The Upper Cambrian or St. Croixan (Potsdam) sandstone occurs in nearly horizontal beds and rests uncomformably upon the Huronian crystalline rocks and the Keweenawan trap. The sandstone extends in a crescent-shaped area around the southeast, south, and southwest sides of the Pre-Cambrian. The narrow northeast horn of the sandstone crescent extends through Oconto and Marinette counties, and into Michigan, while the much broader northwest horn abuts upon the Keweenawan trap along the St. Croix river, in Polk county.

The Potsdam sandstone outcrops over a large area in central Wisconsin and reaches a maximum north-south width of 100 miles or more, while at the northeast horn of the crescent, the width dwindles down to 10 and even 5 miles, leaving only a small exposure of sandstone between the crystalline rocks and the later limestone formations.

While the sandstone has usually been mapped as a single formation or group it really consists of several formations or groups each of which possess a fairly distinct lithologic and faunal character. It was only in certain parts of southern and eastern Wisconsin that certain horizons, such as the Madison and the Mendota beds were recognized and mapped, by Irving and Chamberlin, of the former State Geological Survey,[1] 1874 to 1881.

During the past season of 1913–1914, Dr. E. O. Ulrich of the U. S. Geological Survey, in coöperation with the present State Survey, has been investigating all the Wisconsin formations, from the Upper Cambrian to the Devonian, for the purposes of correlating the several formations within the various parts of the state as well as with formations of similar age outside the state.

In a recent paper by C. D. Walcott,[2] a provisional classification of the pre-Ordovician formations of the Upper Mississippi valley was suggested by E. O. Ulrich which had been based on the short field study of 1913. From additional investigations carried on in 1914, it is evident that certain changes in the provisional classification will have to be made before the final conclusions concerning the thickness, character and correlation of the several formations below the Lower Magnesian dolomites can be reached.

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[1] Atlas of the Geol. Survey of Wis. Plates XIII and XIV.
[2] Smithsonian Institution Collections, Vol. 57, No. 13, p. 354, 1914.

On the geologic map of the state, Plate I, the various formations of the Lower Magnesian and the Upper Cambrian "Potsdam" are referred to in the legend. As these names of formations are likely to be used to a considerable extent in subsequent geologic reports of the state, it seems advisable to present in the table, Plate II, the provisional or tentative classification of these Lower Magnesian and Upper Cambrian formations at the present time, with the understanding that changes are likely to be required in this classification as the several formations are later studied in detail.

In the legend on the geological map, Plate I, the Mendota and Madison formations are described as overlying the Jordan and St. Lawrence formations. However, the formerly accepted correlation of the Madison as essentially equivalent to the Jordan, and the Mendota as essentially equivalent to the St. Lawrence, is probably the correct interpretation, as is indicated in the general geologic section, Plate II.

On the geological map of the state accompanying the present work on the water supplies, Plate I, the Upper Cambrian or "Potsdam" sandstone group includes all beds below the Oneota dolomite, and the Lower Magnesian group includes the two formations, the Oneota and the Shakopee dolomites as these two formations have not yet been mapped separately in the field.

Much of the Potsdam sandstone where it forms the surface rock has been eroded, and in places entirely removed, so that the present area of outcrop, which is about 15,000 square miles, is much smaller than the original extent of the formation. These conclusions are supported by evidence of the occurrence of numerous Potsdam outliers found far out in the crystalline area.

Thickness.—The thickness of the Potsdam sandstone on account of erosion varies greatly. From very thin eroded deposits along its contact with the much older crystalline rocks, the thickness increases, as the distance increases from the crystalline area.

As estimated by Chamberlin, the average original thickness in eastern and western Wisconsin is between 700 and 800 feet, the usual maximum thickness being about 1,000 feet. In southwestern Wisconsin, however, a maximum thickness of over 1200 feet is reached. In northeastern Wisconsin, the average thickness is between 400 and 500 feet. The thickness of the sandstone and its characteristics, as illustrated by well records at various places, may best be obtained from the individual well records described later, under the county descriptions.

Underground Water Conditions.—The Potsdam sandstone is usually poorly cemented and is unconsolidated and varies from a coarse gran-

ular rock to one which is exceedingly fine-grained. Although, as a rule, it is so soft as to crumble in the hands under slight pressure, in a few places, the rock is so firmly cemented by silica or calcium carbonate that it is suitable for use as a building stone. The beds of shaley sandstone vary in thickness from a few feet to over 150 feet.

The pore space between grains of sand in the sandstone, generally comprise 25 to 35 per cent of the rock, in both the pure sandstone and in the shaley sandstone beds. The size of the pores, however, are very much larger in the pure sandstone than in the shaley beds, hence the water-bearing capacity and ease of transmission of water is much greater in the coarse beds. The relatively impervious shale zones divide the sandstone into several water horizons. Although not everywhere continuous, these shales extend over large areas and influence the various heads to which the artesian water will rise in wells drilled into the sandstone within its outcrop area.

Flowing artesian wells are found at various places, as at Sparta, Arcadia, Whitehall, Menomonie, Durand, Elroy, Reedsburg and Baraboo. Conditions for flowing artesian wells are by no means confined to the outcrop area of the formation, but extend throughout the state where the sandstone is covered by many feet of later formations.

In a few places, the water from some of the horizons has a reddish color, and is unfit for drinking purposes. In most cases, it is not very difficult to drill through such horizons and shut off this unfit supply by proper casing. In some localities, wells end in the upper or middle horizons of the Potsdam sandstone in order to avoid the waters highly impregnated with iron which are occasionally found in the lower horizons of this formation.

LOWER MAGNESIAN LIMESTONES

Lying on the Madison or Jordan sandstone, is a group of siliceous dolomitic beds, the Lower Magnesian limestones. It corresponds in part to the calciferous sand rock of Michigan, and essentially to the combined Oneota and Shakopee dolomites of Iowa and Minnesota. (See above classification in the geologic section Pl. II).

These formations of dolomite form a band on the convex side of the Potsdam sandstone. Their outcrop has a varying width from 10 or 15 miles in the northeastern part of the state to 40 or 50 miles in the southwestern part and extends northward along the western part of the state as far as Polk county.

Thickness.—In some localities, the dolomite beds of these formations are entirely lacking. At such places, the well records, as usually stated,

show the passage of beds directly from the overlying St. Peter sandstone into the underlying Potsdam sandstone. In such cases there is a great thickness of St. Peter sandstone that occupies the usual horizon of the Lower Magnesian formations. The thickness of the Lower Magnesian varies greatly, but is usually between 150 and 250 feet. The variation in thickness of the Lower Magnesian and in content of sandstone beds is sometimes very marked.

Underground Water Conditions.—The Lower Magnesian is largely dolomitic limestone, but it also contains varying amounts of siliceous material in the form of scattered and aggregated quartz crystals and beds of flint or chert nodules and variously shaped masses. Beds of sandstone, also of local extent and sometimes of oolitic structure, are distributed rather irregularly throughout the formation. The presence of sandstone toward the base, makes it often difficult, if not impossible, to distinguish this formation in wells from the nearly conformable underlying Potsdam sandstone though a considerable break in sedimentation occurs between. The passage of water through the limestone is greatly aided by systems of joints and fissures, both transverse and oblique to the bedding planes.

The close association of the Lower Magnesian formations of dolomite with the thick Potsdam sandstone below and with the St. Peter sandstone of quite variable thickness above, makes it difficult and usually impractical to consider them separately with respect to artesian conditions where overlain by the thick later formations in eastern Wisconsin. While there is usually an increase in artesian head in passing down from the St. Peter through the Lower Magnesian to the base of the Potsdam, there are many exceptions to the rule, on account of the irregularity in character and thickness of the Lower Magnesian and St. Peter formations.

ST. PETER SANDSTONE

The St. Peter sandstone lies on the eroded and somewhat uneven surface of the Lower Magnesian limestone formation. Along its contact with the underlying limestone beds, is more or less calcareous matter, derived from the formations below. At the base, a little ferruginous and clay material often mingles with the sand and calcareous ingredients, and forms a variegated rock, not unlike the colored shales of the Potsdam. In the upper part of the horizon, usually occurs another shaly seam, very thin and mixed with clay material, upon which rests the Trenton limestone. Usually, however the transition beds are thin and abrupt.

The formation fringes the convex side of the Lower Magnesian limestone (see the geologic map, Pl. I.). It extends under the later formations and underlies the southeastern part of the state, both east and south of its outcrop area. The outcrop has been traced from Marinette county on the east, to Vernon county on the west side of the state. Small outliers are also found in Pierce and St. Croix counties, in the northwest part of the state, near the junction of the St. Croix and the Mississippi rivers. In eastern Wisconsin, its outcrop is very narrow, but it widens around the south end of the crescent, and in the vicinity of Jefferson, Edgerton, and Albany becomes rather extensive.

Thickness.—The thickness of the St. Peter sandstone is very irregular, the usual thickness ranging from 20 feet to 60 or 80 feet. The formation becomes somewhat thinner toward the northeast and probably does not extend very far into the northern peninsula of Michigan. In many places, where the St. Peter sandstone rests directly upon sandstone beds of the Lower Magnesian or the underlying Potsdam, it is impossible to ascertain, in well records, the exact thickness of the St. Peter. Even where the Lower Magnesian limestone beds are present the thickness of the St. Peter apparently varies greatly.

While the thickness of the St. Peter sandstone and of the underlying Lower Magnesian formation of dolomite is usually very irregular, on account of the erosion interval between them, their combined thickness is usually quite uniform. Where the St. Peter formation is very thick the Lower Magnesian formation is very thin, and where the former is thin, the latter is thick. Hence, in stating the approximate thickness of geologic strata in each county, the combined thickness of the St. Peter and Lower Magnesium is usually given as 200 to 250 feet, with the understanding that over such a large area as a county the combined thickness will represent quite variable thicknesses of each formation.

Underground Water Conditions.—The St. Peter sandstone is usually composed almost exclusively of well-rounded quartz grains of medium sizes, in places very coarse and porous. It is weakly cemented by thin coatings of iron oxide and calcium carbonate, is porous and incoherent, and is usually not compact enough to allow handling without crumbling. However, in certain localities, the rock is hard and compact, as at Red Rock, Lafayette county, where the St. Peter sandstone is used for building purposes. The color is chiefly white, varied with yellow, bluish, and gray.

The sandstone is somewhat broken and fissured, both transverse and oblique to the bedding. These fissures and the coarse porous nature of the sandstone make it an excellent water-bearing horizon, and in the

eastern and southern part of the state, it frequently furnishes artesian water, and numerous flowing wells.

As referred to in the above description of the Lower Magnesian dolomites, the Upper Cambrian sandstones, the Lower Magnesian dolomites and the St. Peter sandstone, where overlain by the later thick formations of dolomites and shales in the southern and eastern parts of the state cannot easily be considered separately in deep wells with respect to their artesian supplies, and for this reason the entire thickness of these sandstone and dolomite beds are conveniently referred to as a unit, or single group, in their relation to deep artesian supplies.

GALENA-PLATTEVILLE (TRENTON) LIMESTONES

The Galena-Platteville limestones consists of two well-defined members, both dolomitic limestones. The lower member, the Platteville, however, contains some pure limestones. In a considerable portion of the state, the Platteville and the Galena have not been mapped separately, and hence are shown by the came color on the accompanying geological map, and they will therefore, be treated as one formation in this report. In Pierce county, the Decorah shale, 30 to 40 feet, thick, is present, lying between the Platteville and the Galena. In other parts of the state the Decorah appears to be represented by dolomite beds.

The formations have a relatively large areal extent in Wisconsin. They extend from Marinette County on the northeast, to the southwest side of the state near the Mississippi river in Central Vernon county. Small outliers are also found capping the hills in Pierce and St. Croix counties, northeast of the junction of the St. Croix and Mississippi rivers. Their extent and irregularities of outcrop as well as the manner in which they fringe the Lower Magnesium and St. Peter formations, may be seen best on the geological map.

Thickness.—These formations, in common with the other sedimentary formations, dip gently to the east and southeast on the eastern side of the state, and to the southwest on the west side. The thickness of the Galena-Platteville is somewhat irregular, but generally varies from 250 to 350 feet, where it is fully preserved, to only a few feet, where it has been largely removed by erosion.

Underground Water Conditions.—The Galena-Platteville formations consist of blue and buff dolomite, containing in the upper horizon many flint and cherty nodules. The texture is somewhat open, but becomes more close-grained with depth. In the lower horizon the dolomite beds are interlaminated with beds of clay and shale several feet in thickness.

The various shale beds and the oil rock form first-class impervious

basements that largely control the underground circulation within this formation. Not infrequently in this formation, are interstratified beds of water bearing sandstone which are several feet in thickness and are composed of nearly pure sand. Over limited areas in eastern Wisconsin, these sandstone layers form an important part of the formation. They are usually thin, however, and of irregular distribution. The Galena-Platteville is an important water-bearing horizon, mainly, only in its general area of outcrop in southwestern Wisconsin.

CINCINNATI SHALE

The Cincinnati (Maquoketa) shales rests nearly conformably on the Galena-Platteville limestone. This formation is composed largely of bluish and greenish shale, with occasional thin beds of limestone. Some of the shales are fine, soft, and even textured and contain a little grit and sand. Others are more slaty in structure, and split readily into thin plates, while some are sandy and more closely resemble soft fine-grained sandstone. The softness of these shales causes them to be easily eroded and they are, therefore, seldom exposed, but lie close to the base of the overlying outcrops of Niagara limestone. This shale formation is found, mainly, in the eastern part of the state.

Thickness.—The thickness appears to vary considerably. For the most part, it is 150 to 250 feet thick, but it increases in thickness to the northward. Along the east shore of Green Bay, it reaches a thickness of 540 feet as shown by the records of wells in this locality. Farther east at St. Ignace, Michigan, Dr. A. C. Lane estimates that the thickness may reach 600 feet or more.

Underground Water Conditions.—This formation is of no value as a water-bearing horizon or stratum, but it forms a good impervious basement for the overlying water-bearing strata. Along its outcrop are located many fine springs.

CLINTON BEDS

The Silurian system is represented in Wisconsin by the relatively unimportant beds of Clinton iron ore, and the very thick formation of Niagara limestone. The Clinton beds are very poorly represented within this state. The Clinton sandstones, shales, and limestone, so characteristic and well developed in New York and other Eastern states, are not represented in Wisconsin.

The iron ore formation at Iron Ridge and Mayville is about the only member of the Clinton epoch in Wisconsin. The ore rests upon the soft

Cincinnati shale at various places, being between the shale and the overlying Niagara limestone. The ore deposits are peculiar in their occurrence and distribution. They form irregular lenticular beds of iron ore, composed of small concretions of hematite, resembling "flax seed". Its maximum thickness of about 25 feet is reached at Iron Ridge, Dodge County. The beds seem to occupy limited depressions in the surface of the underlying Cincinnati shale. It is unimportant as a source of water supply.

NIAGARA LIMESTONE

The Niagara limestone forms a broad belt in the eastern part of the state, along the shore of Lake Michigan. It extends as a continuous formation, from Door County on the north, to Kenosha County on the south, and forms the summits of isolated mounds farther to the southwest, as illustrated in the Blue Mounds and the Platteville Mounds.

The Niagara is a pure dolomite and in places it resembles the limestone of the older metamorphic formations very closely. The number of beds composing the formation is greater in the north-central part of the belt than farther south. Chamberlin, in his report on Eastern Wisconsin,[1] divides the Niagara in the south, into four groups of beds, while in the north, he recognizes six. In some places these beds are uniform in color and texture, while in others they possess many irregularities. The upper part of the Niagara limestone is highly siliceous and cherty. The limestone beds are of varying colors; gray, blue, white, and buff being common.

Thickness.—The thickness of the formations is somewhat irregular, varying from 200 feet in the southern part of the district to over 600 in the central and northern part. The greatest thickness apparently occurs at about the center of the limestone belt in the vicinity of Sheboygan. North of Sheboygan only two wells have penetrated the Niagara limestone; one at Two Rivers; the other at Algoma. From these records it is apparent that the thickness in the northern half of the belt is considerably greater than in the southern half.

Underground Water Conditions.—In places, the beds are coarse, crystalline, and granular, somewhat inclined to be soft, and occasionally earthy. Other beds of siliceous limestone, closely resembling sandstone, are not infrequently entered by the drill. These sandy beds, and some of the more porous limestones, are the chief aquifers found in this horizon. The Niagara limestone, as a whole, is fairly well intersected by transverse and bedding joints, which greatly increase its permeability,

[1] Geol. of Wisconsin, Vol. II. pp. 335–390.

and it is, therefore, the chief source of water supply for many of the wells along the Lake Michigan shore. Flowing wells are obtained at various depths in this horizon in eastern Wisconsin.

WAUBAKEE BEDS

Near the village of Waubakee, in Ozaukee county, and also near North Milwaukee, are beds of brown shaly limestone having a total thickness exposed of 10 or 12 feet, whose stratifraphic position was formerly referred to the Lower Helderburg, but which has recently[1] been placed in the Cayugan group, and given the local name of Waubakee beds. Similar beds occur under the Hamilton cement rock in the quarry of the Milwaukee Cement Company. In the deep artesian well at Lake Park, about 30 feet of brown limestone was passed through, overlying the Niagara group, and about 10 feet of the same limestone lies between the Hamilton beds and the Niagara group at the intake tunnel at North Point.

The Waubakee beds are correlated with the Silurian. The formation is not important as a water-bearing horizon.

HAMILTON SHALE FORMATION

The Devonian system is very incompletely represented in Wisconsin. Only a few limited patches occur and these have only a local interest as water-bearing horizons. The Hamilton (Middle Devonian) occurs in two localities. Outcrops of Hamilton rock on the shore of Lake Michigan indicate an area of this limestone in the vicinity of Milwaukee[2] and another area in the vicinity of Lake Church, ten miles north of Port Washington.[3] These remnants in the vicinity of Milwaukee lie along the lake shore immediately north of the city limits and are exposed, in places, over an area about 6 miles in diameter. It rests in part upon the laminated Waubakee shales, in part upon the Niagara limestone. The deposits consist of a bluish-gray or ash-colored impure dolomite broken into layers by seams of clay. The limestone layers vary from homogeneous to lumpy texture, and the upper layers are sometimes shaly. Their thickness varies from a few inches to 3 feet of heavy-bedded limestone. The intercalated clay seams vary from 0 to 5 inches in thickness. The

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[1] W. C. Alden, Prof. Paper 34, U. S. G. S. p. 13–14; Folio No. 140 U. S. G. S.

[2] Teller, E. E., The Hamilton Formation at Milwaukee, Wisconsin, Bull. Wisconsin Nat. Hist. Soc., Vol. 1, pp. 45–56.

[3] Monroe, Charles E., "A Notice of a New Area of Devonian Rocks in Wisconsin Journal of Geology, Vol. 8, p. 313, 1900. Clelland, H. F., "Middle Devonic of Wisconsin"., Bull. Wis. Survey No. XXI.

total thickness is here about 26 feet, and the slight dip is southeastward. The shafts and tunneling for the present water supply of Milwaukee are, for the most part, in these rocks and in the underlying Waubakee beds.

PLEISTOCENE FORMATIONS

All the formations thus far considered consist of indurated or hard rocks. Lying upon the hard rock formations in most parts of the state, are glacial drift deposits consisting of unconsolidated clays, sands, gravel and boulders. While the indurated rocks were mainly deposited as marine sediments, the unconsolidated deposits were mainly the result of glacial and river action.

Three-fourths of the state, the southeastern, the eastern and northern parts are covered with a variable thickness of drift. In the central and southwestern parts, known as the "Driftless Area", no glacial deposits occur. In the driftless area, however, there is usually present on the uplands, a variable thickness of loess, or of residual or colluvial soil, while the valleys are usually filled with thick deposits of alluvial sand and gravel.

THE GLACIAL DRIFT

The drift was deposited over the glaciated parts of the state by several ice invasions, probably four or five, separated by inter-glacial periods. The loose material deposited by the glaciers was distributed irregularly over the surface, either in the form of extended sheets of drift, or as terminal moraine ridges. The nearly level areas constitute the so-called ground moraines, composed of sand, gravel, boulders, and clay, variously arranged and spread irregularly upon the rock surface. The terminal moraines occur as small knolls and ridges and basins with a characteristic surface which is more or less undulatory.

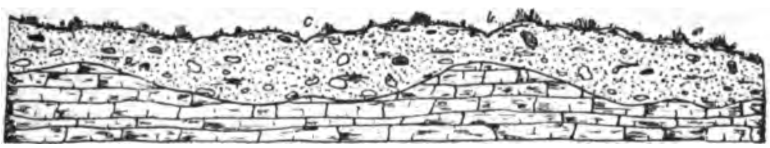

Fig. 2.—Diagrammatic section showing thick drift over rock.

Thickness.—The thickness of the drift generally varies between a few feet up to 100 feet. In those glaciated parts of the state where preglacial valleys exist, or where the drift is in morainic ridges, the thickness usually exceeds 100 feet, and often reaches 200 or even 300 feet. The irregular thickness of the drift is illustrated in figures 2 and 3.

Underground Water Conditions.—As much of the drift occupies the upland areas and the stream divides, it receives most of its water direct from the rainfall. The drift in valleys, however, doubtless receives an additional supply by seepage from the rock, and also from the drift lying on the higher slopes.

Fig. 3.—Diagrammatic section showing thin drift over the underlying rock.

Much of the drift is composed of a heterogeneous mixture of clay, sand, and boulders, and the amount of water absorbed by the drift depends on the proportion of these constituents in the deposits. The larger the percentage of sand in the drift, the larger is the amount of water absorbed, and the more readily it circulates through the deposits. In general the latest drift sheet, the Wisconsin, contains more sand, and is also less consolidated, than the older drifts, hence it is a better water-bearing formation than the older drift. In the low flat areas of drift the water table generally approaches very close to the land surface.

The terminal moraine deposits which form the hilly and undulating "Kettle Range" of the state, generally consist of more porous drift than the level till plains, and are usually well supplied with groundwater. These terminal moraine deposits overlie the older till plains, and springs often issue along their borders. The terminal moraines contain many basins occupied by lakes and marshes from which there may be seepage into the outlying lower drift. Most of the wells in the terminal moraines obtain their supply of water from the beds of gravel interstratified with the drift. The depth at which the water is obtained in the moraines, is somewhat irregular, but usually the water is found near a common level for any locality.

LACUSTRINE AND ESTUARINE DEPOSITS

Associated with the terminal and ground moraines are those forms of deposits that have been modified by the glacial rivers or by local marginal lakes. In these deposits a portion of the glacial drift has been sorted and worked over by the water and deposited in stratified beds of clay, sand, and gravel. In certain localities such accumulations of

stratified beds consist of alternating pervious and impervious material, giving rise to local artesian areas.

Beside the above mentioned stratified beds, we have the much more extensive lacustrine and estuarine deposits mainly near the shores of Lake Michigan, Green Bay, and Lake Superior. The material composing these deposits consists chiefly of silt, sand and gravel, covered with stratified beds of clay. They were probably deposited in the waters of expanded interglacial or glacial lakes, the predecessors of Lake Superior and Lake Michigan, and in interior lakes and estuaries. The clay contains much calcareous sediment, probably mainly of organic origin which is stratified with the silt and sand.

Underground Water Conditions.—The lake clays which border the shore of Lake Michigan and Lake Superior, and extend for some distance up the Green Bay and Fox river basins, are important as impervious confining strata to the water-bearing sands and gravels with which the clays are interstratified or upon which they lie. As a result of the presence of the overlying clays, the groundwater in the underlying sand and the gravel beds is held under hydrostatic pressure, and where the deposits are in basins and along slopes, flowing wells are readily obtained.

The lacustrine formations, therefore, are important in the development of conditions for shallow artesian slopes, in which the flowing wells are generally less than 100 or 200 feet deep and are wholly confined to the superficial deposits. The source of the water is mainly by seepage along the higher slopes of the basins, though in some instances the water is probably fed from the underlying indurated rocks.

VALLEY ALLUVIUM

Along all the large rivers of the state occur deposits of gravel, sand, and clay. Many of the valleys within the driftless area are filled to a depth of 100 feet to 200 feet, or more, with river-washed sand and gravel. Many of the large rivers of the driftless area were drainage channels for water during the melting of the ice sheet, as well as during the interglacial stages. In this way glacial material was taken by the rivers into the valleys of the driftless section.

The alluvial deposits form the low, nearly level, sandy lands along such large streams, as the Mississippi, the Wisconsin, the Chippewa, the St. Croix, and many other large rivers and their important tributaries. In many places the alluvial estuarine and lacustrine deposits grade into one another. They appear to indicate a period of low eleva-

tion of the land with many lakes and sluggish rivers, during middle Pleistocene time.

Some of these rivers have alternately eroded and filled their valleys several times, as may be seen from the series of terraces along their courses. On the lower Chippewa river, as many as five distinct terraces may be seen above the present river bed. The highest terraces are from 80 to 125 feet above the Chippewa, Black, and Wisconsin. The level surface of the highest terraces stretches back on either side of the river to the undulating uplands of indurated rock. (See Figure 4.)

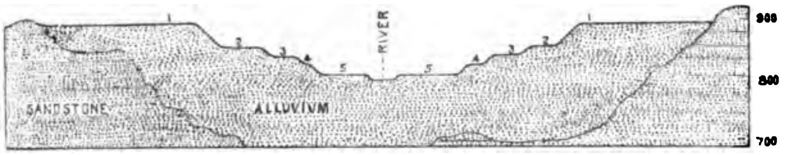

Fig. 4.—Section showing terraces in the Chippewa Valley below Eau Claire.

Where tributaries join the main streams, low bottom-lands are formed, stretching for some distance back along these branches. The lowest terraces or "bottoms" are separated from the older and higher terraces by steep slopes, varying from 5 to 30 feet in height.

Underground Water Conditions.—Many cities and villages, as well as the farms located upon these river terraces, draw their supply of water from the sub-soil of river-washed sand and gravel. The water level usually lies from a few feet to a hundred feet below the surface, and a sufficient supply of water is readily obtained from dug or driven wells sunk into this formation.

The stratification of the alluvial gravels, sands, silts, and clays is similar to that of the lacustrine deposits; in fact, lacustrine and alluvial material are often interstratified with each other, not only in the glaciated areas, but also in the driftless region. The interbedded gravels, sands, and clays in the valleys, give rise to the development of artesian slopes, in the same manner as the lacustrine deposits fringing the basins of Green Bay and of the Great Lakes. In nearly all the valley alluvial deposits, shallow flowing wells have been obtained, as illustrated by the flowing wells along the tributaries of such rivers as the Wisconsin, the Baraboo, the La Crosse, the Chippewa, and the St. Croix.

There is a larger proportion of water-bearing strata, such as sand and gravel, in the purely alluvial deposits, than in the lacustrine deposits. The areas of flowing wells in the valley deposits are usually, if not always, more irregular, and the artesian pressure or head is more variable than in the artesian areas of the lacustrine deposits, due in

part to the fact, that the confining strata of clay are not so thick or so continuous in the valley alluvium as the clays in the lacustrine deposits.

LOESS

Loess of eolian, or wind origin, consisting mainly of silt and fine sand and a small amount of clay, forms fairly abundant deposits overlying the rock in the southwestern and northwestern parts of Wisconsin. The mantle of loess is mainly restricted to the driftless area in southwestern Wisconsin and the regions of the old drifts in the northwestern part of the state, extending as far north as Pierce, Dunn, and Chippewa counties.

The distribution and thickness of the mantle of loess is somewhat irregular within the general area of its occurrence, usually being thick and more continuous along the Mississippi river and thinning out gradually to the east, the border generally being within 50 to 75 miles east of the Mississippi.[*] Its thickness generally varies from a few inches to 10 or 12 feet on the uplands. During the long period since the loess was deposited, much of it has been washed from the uplands and slopes into the valleys, where it overlies, or is mingled with, the valley alluvium.

Underground Water Conditions.—The loess consists of 50 to 75 per cent of silt, the remainder being mainly fine sand and clay. In general it is of quite porous texture, though quite fine-grained. It has the capacity to absorb the rain quite readily, and unless rains are copious most of it sinks into the loess.

The deposits of loess on the uplands are very generally too thin to furnish water in wells. Occasionally, however, shallow wells in relatively thick deposits in wet seasons furnish small supplies on the farms. The loess mantle exerts a good influence in conserving groundwater as soil moisture for the growth of crops, and only relatively slowly allows the seepage of groundwater to the underlying rocks, where it later becomes a source of water supply in wells.

CHAPTER II.

CONDITIONS CONTROLLING MOVEMENT OF LOCAL UNDERGROUND AND ARTESIAN WATERS

The body of underground water has its source in the precipitation which falls upon the earth, and is transmitted below the surface through the various pores and openings in the under-lying rock formation. The total precipitation, as already stated, can be divided into three parts: (1) That which is evaporated directly or is transpired by vegetation; (2) That which runs off the surface at once; (3) That which is absorbed and becomes underground water.

Underground water, therefore, is water from any source which is below the earth's surface. The underground water receives practically no supply from the lakes and rivers, but on the contrary, the streams and lakes receive their permanent supply from the body of groundwater in the rocks.

Local Underground Water and Artesian Water

The underground waters are conveniently described in two groups: (1) Those that are termed shallow or local waters, as they are fed by local rainfall absorbed through the soils directly above, and are sometimes referred to as local underground waters, and (2) Those that are confined under pressure within the rock strata and to some extent have been transmitted laterally for some distance underground from the point fed by local rainfall, and are termed *artesian* waters.

The distinction between the country rock water or local groundwater and artesian water in many localities can not be always sharply drawn. In accordance with present usage, the term "artesian" is applied, not only to the water of flowing wells, but also to the water in non-flowing wells which rises to a considerable height in the well tube above the source of supply.

The Local Groundwater

The movement of local groundwater is both downward and laterally. It moves mainly downward to the level of the groundwater table, to the groundwater level, below which all the pore spaces and openings in the rocks are filled with water. After it reaches the groundwater level of the locality it flows mainly in a lateral direction.

Movements in the Surface Zone.—The unsaturated surface zone, or partially saturated zone of flow of ordinary groundwater, extends from the land surface down to some distance below the top of the fluctuating water table. In coarse loose material the rapidity of the movement of the water is much greater than that in fine-grained clays. The water near the surface of the water table also moves laterally much more rapidly than that more deeply situated. Near the surface of the water table there is a close agreement in the direction of the movement of the groundwater and the slope of the land surface. This is especially true in the superficial deposits of drift and alluvial sands.

Depth to Groundwater Level.—Because the surface over a large part of northern and eastern Wisconsin is relatively flat or gently sloping the groundwater level, in many places, is within only a few feet of the surface. In many instances, in flat lying areas, where the groundwater level is near the surface, a common cistern pump, with its cylinder above ground, is used to raise water for domestic purposes.

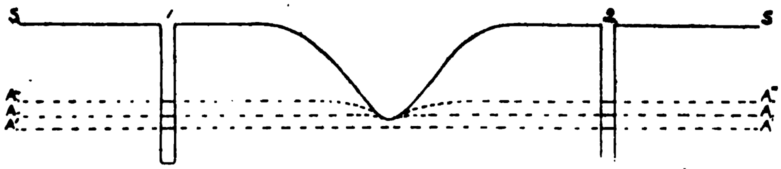

Fig. 5.—Diagram illustrating relations of groundwater to streams and wells. The dotted line AA represents the usual groundwater level which rises to A" A" in wet seasons and sinks to A' A' in dry seasons.

In the hilly and more undulating parts of the state, like that portion adjacent to the Mississipi river, the water table, or the surface of the underground water, conforms primarily to the grades and slopes of the surface. In the valleys, the level of the groundwater stands very near to the surface, while on the slopes and hills it often stands 50 to 200 feet below. The water table in Wisconsin is usually at a depth of 20 to 50 feet, seldom lower than 80 feet in the gently sloping part of the state. In the driftless area and in the undulating and hilly parts of the state there is the greatest variation in the level of the water table, the usual depth being from 50 to 200 feet below the surface.

Change in Groundwater Levels.—The head of the groundwater, or groundwater level, rises and falls from season to season depending upon the seasonal rainfall. It also changes locally from year to year, due to variation in amount of annual rainfall. The groundwater is appreciably lowered where considerable pumpage from wells takes place. The relation of the groundwater level to streams and wells is shown in Fig. 5.

ARTESIAN WATER.

In many parts of Wisconsin the water in certain beds is under sufficient hydrostatic pressure to cause it to flow above the surface when penetrated by driven or drilled wells. The flowing wells are much prized as they furnish a continuous supply of fresh, pure water, and are essentially free from all possible sources of contamination. The flowing artesian wells have their source in the rock strata, mainly the St. Peter and Potsdam sandstone, and in the surface formations of glacial drift and of alluvial or lacustrine silts, sands and gravels. As the factors controlling the occurrence of artesian flows in the indurated rock and in the surface formations are somewhat different, the artesian wells from these two sources will be described separately.

Definition of artesian water.—The term "artesian" has been often used to convey different meanings, but in this report, following the usage now prevailing, artesian water includes all underground water held under pressure whether the wells are flowing or not. In nearly all cases, the only difference between a non-flowing artesian well and a flowing artesian well, is due to the difference in the relative elevation of the surface of the ground at the wells.

Artesian head.—Under artesian pressure, the water rises in the well tubes above the water bearing stratum that is pierced by the drill hole. The water may rise high enough to overflow above the surface or it may fall short of reaching the surface. The height at which the artesian water ceases to rise or exert upward pressure, is called its static head or level. The head may be expressed in relation to the sea level, the altitude, or to the surface of the well curb.

Measurement of head.—The head of flowing artesian wells may be measured at the well mouth, in pounds per square inch by means of a gauge, and the head then computed in feet. As a column of water one inch square and 2.3 feet high weighs one pound, the number pounds pressure at the well multiplied by 2.3 equals the head in feet. The head may also be measured by tubing coupled water-tight to the well-casing and carried up a trestle or ladder until the water stands at the

top but does not overflow. To obtain the true hydrostatic pressure, the measurement should extend over several days and for this reason the use of the pressure gauge is most convenient.

Conditions Controlling Artesian Supplies.

The movements of the deeper underground or artesian water under hydrostatic pressure, are determined by a somewhat different set of factors from those controlling the movement of shallow or local rock water near the surface. Much has been written by various authors concerning the leading conditions upon which flowing wells depend. Prof. T. C. Chamberlin's[1] classical article on the "Requisite and Qualifying Conditions of Artesian Wells", is one of the best general treatises upon the subject. Prof. C. S. Slichter's[2] report on "The Motions of Underground Waters" clearly shows the difficulties that may arise when large drafts are made upon a subterranean basin. A recent contribution by Myron L. Fuller[3], "Summary of the Controlling factors of Artesian Flows" is an excellent condensed statement of the subject.

The principal conditions and requisites on which flowing wells in stratified beds depend were summarized by Chamberlin in 1885 as follows:

"1. A pervious stratum to permit the entrance and the passage of the water.
2. A water-tight bed below to prevent the escape of the water downward.
3. A like impervious bed above to prevent escape upward, for the water, being under pressure from the fountain-head would otherwise find relief in that direction.
4. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface of the well.
5. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
6. An adequate rain-fall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface of the well."

The three essential factors for the development of artesian flows in all kinds of rock recognized by M. L. Fuller are as follows:

"1. An adequate source of supply.
2. A retaining agent offering more resistance to the passage of water than the well or other opening.
3. An adequate source of pressure."

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[1]Geol. of Wis. Vol. 1, 1881, p. 689–701. Fifth Annual Report U. S. Geol. Survey, 1885, pp. 125–173.
[2]Water Supply & Irrigation Papers U. S. Geol. Survey, No. 67, 1902.
[3]Bulletin No. 319, U. S. Geol. Survey, 1908.

There are, however, many other factors modifying artesian flows referred to by Fuller as secondary factors, as follows:

Secondary factors of artesian flows.

- I. Hydrostatic factors (relating to pressure and movement).
  - 1. Factors mainly affecting pressure.
    - a. Barometric pressure.
    - b. Temperature.
    - c. Density.
    - d. Rock pressure.
  - 2. Factors mainly affecting movement.
    - a. Porosity.
    - b. Size of pores or openings.
    - c. Temperature.
- II. Geologic factors (relating to reservoir).
  - 1. Character of reservoir.
  - 2. Retaining agents.
  - 3. Structure of reservoir.
  - 4. Topographic conditions.
  - 5. Conditions relating to supply.
    - a. Catchment conditions.
    - b. Conditions of underground feed.
  - 6. Conditions of leakage.

Although the basic principles of artesian wells are simple and easy to understand, many of the practical problems associated with them are often varied and complex, involving the most careful study and attention.

All of the foregoing requisite and qualifying conditions for artesian systems may occur in the same region at different depths, giving rise to independent systems differing entirely from one another in geologic origin and structure. Such is often the case in Wisconsin, as shown by the fact that artesian waters are found in various geologic horizons, some of the horizons being quite similar while others are quite unlike in structure and origin.

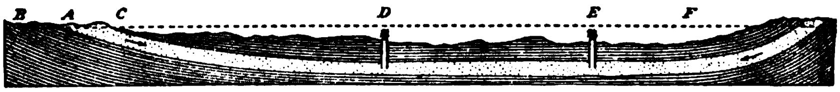

Fig. 6.—Section of an artesian basin. *A*, Porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous beds *A*, or, in other words, height in reservoir or fountain head; *D*, *E*, flowing wells springing from the porous water-filled bed *A*.

No attempt will be made to present a complete discussion of all the important factors modifying and controlling artesian flows in this report. For a short and fairly comprehensive discussion, the reader is referred to the Bulletin No. 319 of the U. S. Geol. Survey, by M. L. Fuller.

Artesian Basins and Artesian Slopes.—While the most common artesian system is generally supposed to be the artesian basin, it is in re-

ality far less common than the artesian slope. A section of an artesian basin is illustrated in figure 6, and of an artesian slope in figure 7.

It may be recalled that the dominant geological structure of Wisconsin is a broad anticlinal fold with the arch of Pre-Cambrian granitic rocks in the north central part, and the overlying Paleozoic strata dipping down towards the outer boundaries of the state. It is along the slopes of the anticlinal arch that the waters within the Paleozoic water-bearing strata are confined under artesian pressure, and it is therefore, in artesian slopes, between the center and the outer boundaries of the state, that artesian areas in the Paleozoic strata are developed.

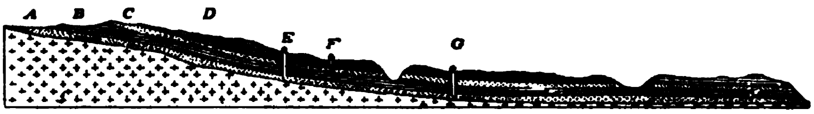

Fig. 7.—Section of an artesian slope. A and C are water-bearing beds; B and D are relatively impervious beds acting as confining strata; E, F and G are flowing wells springing from the water-bearing beds.

The artesian slope is characteristic not only of the Paleozoic strata but also of the surface deposits of the Pleistocene. While completely enclosed basins may be developed occasionally in the surface deposits adjacent to lakes, it is most usually the case that the areas of surface flows are dependent upon the development of structural conditions favorable to the flow of the underground water down the valleys, as illustrated by the artesian wells in the surface deposits about Lake Poygan and Lake Winnebago in the Fox river valley, and by the artesian wells in the Potsdam sandstone in such valleys as the La Crosse, Kickapoo, and Baraboo rivers.

An important, though by no means, necessarily essential, factor in the development of effective artesian pressure is the presence of pervious beds that are continuous with the porous beds of the outcrop. Fissures and crevices in the overlying or underlying rock which are in direct communication with any collecting area, or any porous vein that serves as a water carrier may develop effective artesian presure. The continuous beds of pervious rock, however, are the most reliable sources of artesian wells. The fissures and porous veins although they furnish an abundant supply of water in many artesian wells, are easily influenced by adjacent wells and are more irregularly distributed and therefore not so easy to strike.

Transmitting beds.—The transmitting beds may all be united into one large porous bed, or they may be separated, as in the Potsdam sand-

stone, into numerous beds independent of one another. Their usefulness depends upon numerous factors, such as the continuity of the beds, the porosity, the fineness of grain, and the mixture of fine and coarse material. The Wisconsin water-bearing formations consist in large part of sand, gravel, sandstone, sandy limestone, conglomerates, boulders, and other material of loose granular texture. In some of the beds may be found almost every possible intermixture of coarse and fine material. In places fine sand, shale and clay are interspersed to such a degree that the water-bearing capacity of the beds is greatly reduced or completely destroyed. Porosity in the transmitting beds as well as in the outcrop rock is a very important consideration, when the volume of flow is taken into account. This condition of porosity varies greatly thus making it impossible to formulate any set rule. For the most part, however, the porosity of the water horizons or water-bearing beds of sands and sandstones is equivalent to, if not greater than that of the most porous sandstone[1], used for building purposes.

Darton[2] estimates the rate of flow of water in the sands of the Dakota sandstone, from which the remarkable artesian wells of South Dakota draw their supply as not exceeding a mile or two a year. It is very probable that in the Wisconsin sandstones the velocity in many cases does not exceed 0.25 miles per year and seldom reaches 0.50 miles per year. The movement may be even much less than 0.25 miles per year.

The velocity and flow of ground water through the various materials under a 10 foot gradient has been calculated by Prof. C. S. Slichter. For a complete discussion of the principles underlying the motions of underground water the reader is referred to various papers[3] cited below.

The leading factor in artesian circulation is gravity which determines the amount of the pressure. Three essential conditions control the amount of pressure. (1) The elevation of the gathering ground above the artesian slope or basin where the wells are located, (2) the degree of slope of the pervious beds from the intake area to the region of the wells, (3) the presence of an overlying and underlying impervious

[1]Wis. Survey Bulletin No. 5, p. 402–3.

[2]Darton: New Developments in well boring and irrigation in eastern South Dakota, Eighteenth Ann. Rept. U. S. Geol. Survey, 1897, p. 609.

[3]Slichter, C. S., Motion of Underground Waters, Water Supply and Irrigation paper, U. S. Geol. Survey, No. 67.

King, F. H., Principles and Conditions of the Movements of Groundwater, Nineteenth Ann. Rept. U. S. Geol. Survey, P. 2, 1899, p. 50.

Slichter, C. S., Theoretical Investigation of the motion of ground-waters, Nineteenth Ann. Rept. U. S. Geol. Survey, P. 2, 1899, p. 285.

stratum for transmitting the water. When the water is confined in porous beds without means of escape, the aquifer becomes a great reservoir. In regions of sufficient rainfall, as in Wisconsin, this reservoir is kept filled to the level of the gathering ground, or to that height at which the water may escape from the confining beds. When the aquifers thus are saturated any increase of the rainfall has little or no effect, for the excess flows away on the surface, or is lost by evaporation, and fails to relieve any stringency that may be due to an excessive loss of water from artesian wells in a local district to which the excess water can not readily be transmitted.

It is usual, though not always essential, as pointed out later, that the gathering ground be higher than the region of the wells from which a flow is expected, so that there may be a sufficient head to insure a flow in spite of leakage through confining beds, and obstructions to passage of water within the aquifers themselves. The steeper the surface gradient from the outcrop down to the mouth of the well, the greater the pressure at the well and the higher will the water rise, if the other factors remain constant.

In its action, an artesian slope in stratified rocks into which wells have been sunk may be compared to a city water works plant. The outcrop corresponds to the standpipe, the aquifers to the mains, and the wells to the private taps in the houses. To make the analogy more complete the standpipe and mains may be considered filled with pebbles and coarse sand so the water can only occupy the pore spaces between them, thus retarding the motion of the water through the pipes.

Available Artesian Head.—In Wisconsin, the outcrop of the artesian water-bearing stratum, mainly the Potsdam sandstones, lies only a few hundred feet above the lowest ground within the state and the lower edge of the porous outcrop is considerably lower than the surface of the divides in the artesian districts. In these inter-stream areas, although the water often rises in the wells considerably higher than at points where flows are obtained in the valleys, it will not rise to the surface on the divides. Since the difference in elevation between outcrop area and artesian area, under the most favorable conditions, over most parts of the state, lies between 600 and 1000 feet above tide, it cannot be expected that water will be forced very high above the surface when deductions for frictional resistance and leakage have been made.

If an artesian basin or slope is again compared to an artificial system, some of the Wisconsin artesian areas are like systems in which the standpipes are low and some of the taps or faucets are a little higher

and some are on a level with the standpipes. In both these cases the water would have to be raised a short distance by pumping. On the other hand other artesian areas in Wisconsin are more favorably situated and are like systems in which all of the taps are considerably below the level of the water in the standpipes and would therefore obtain flows.

However, elevation of the well with respect to the feeding area, as will be shown later, is not the only factor to be taken into consideration before predicting whether a flow can be obtained. Many other factors must be taken into account such as distance of the well from source of supply, the porosity of the beds, the nature of the confining beds, temperature, kind of well, continuity of water-bearing beds, and the relation of the local ground-water table.

Confining beds.—Water confined to the aquifers under hydrostatic pressure has a great tendency to seek the level of its sources. It is, therefore, necessary that the water be imprisoned in the aquifers, otherwise the artesian effect will be lost. This is usually accomplished by layers of impervious rock (or their equivalents), either above or both above and below the porous rocks. The best impervious layers are heavy clays, as they are practically water tight. Others less effective are shales, slates, shaly limestone, limestone, argillaceous sandstone, and crystalline rocks.

As no rock or stratum is entirely impervious and free from minute partings and pore space, no rock is absolutely impenetrable to water. Therefore, some of the water always escapes, the amount increasing as the pressure and temperature increases. It is, however, not necessary to confine all of the water, but only enough to make the aquifer serviceable. In Wisconsin, the lowest water-bearing formation, the Potsdam sandstone, is underlain by impervious crystalline rock which cuts off the downward escape of the water. In the formations above the Potsdam there are numerous beds of shale and limestone which act as impervious basements for higher aquifers. It is of much importance, though not essential that upper beds be impervious for the most favorable development of artesian conditions. Loss in pressure may also result if overlying beds are cracked and fissured, or are displaced by faults which offer a ready upward passage to the water.

Complete destruction of artesian conditions or the rapid decline in the artesian head, may result from the opening of terminal escapes for the water as in the deep, pre-glacial valleys of southern and southwestern Wisconsin. The aquifers in the Potsdam sandstone have there been dissected sufficiently by the rivers to offer the local groundwater as well as the artesian water a ready means of escape.

In artesian slopes situated near the Great Lakes, as well as in those areas where the aquifers have been cut across and drained by drift-filled pre-glacial valleys, or where the aquifers have been cut by fissures or faults, a possible terminal escape must always be taken into account. Artesian water is lost by terminal escape, by slow leakage through the confining strata, and by leakage at the well itself, either between the casing and rock or through the corroded casing. Where many of the old wells have been abandoned, as at Fond du Lac and Watertown, the head of new wells may be greatly lowered by the escape of water from these wells into the overlying drift.

Terminal escapes occur at various places in Wisconsin, not only in the deeper artesian zones, but also in local shallow artesian slopes in glacial drift. In various places within the state there is less hydrostatic pressure than should be expected, probably because of the development of pre-glacial erosion of a terminal escape for the underground water. However, erosion does not always completely destroy the artesian conditions as soon as an aquifer is exposed, for associated lower impervious beds may effectually confine the water. A typical case of this kind occurs at Prairie du Chien, where the upper part of the Potsdam has been eroded and the ancient valley offers an escape to the water from the upper horizon; but the next underlying confining bed is not quite cut through so an abundant supply of artesian water can be obtained from the Potsdam aquifers only a few feet below the old valley. Although not destroying completely the artesian conditions, terminal escapes are always a potent factor in modifying them.

Influence of the local ground water table.—It seems very apparent, that the height of the local water table is a very important factor in determining the artesian head in any locality. The stratified beds of sand, shale, and limestone which constitute the artesian group, appear to be especially favorable to the transmission of pressure from the overlying water table to the confined waters within the artesian reservoir. While the artesian reservoir is separated into beds of varying degree of imperviousness, the presence of vertical joints ramifying throughout the group, as well as the sandy and semi-porous character of the beds as a whole, furnish conditions favorable to the transmission of water and pressure from above.

Prof. Chamberlin[1] appears to have first pointed out the relation between the height of subterranean water level and that of the artesian head. He says:

"If the subterranean water stands as high as the fountainhead (ex-

[1]Fifth Ann. Rept. U. S. Geol. Survey, p. 140, 1885.

cept at the well, where of course, it must be lower) there will be no leakage, not even if the strata be somewhat permeable, for the water in the confining beds presses down as much as the fountain-head causes that of the porous bed to press up, since both have the same height.

"If the water between the well and fountain head is actually higher than the latter, it will tend to penetrate the water-bearing stratum, so far as the overlying beds permit, and will, to that extent, increase the supply of water seeking passage through the porous bed, and will by reaction, tend to elevate the fountain head if the situation permit.

"If, on the other hand, the water surface is considerably lower than the source there will be considerable leakage, unless the confining beds are very close-textured and free from fissures."

The height of the water table over many points in the artesian systems of Wisconsin undoubtedly exerts a strong influence on the pressure, and in many places is a far more important factor than the pressure transmitted through continuous water bearing strata, from the more remote catchment area.

As pointed out by Fuller[1], while the level of lakes and streams is commonly a function of the height of the ground-water in the vicinity, yet sometimes the reverse is true and the ground-water level becomes a function of the level of the water bodies on the surface. The latter may also in some cases influence to a considerable extent the pressure on underlying confined waters. Fuller, summarizes the effects of surface water bodies on the underground water as follows:

Effects of height of surface water bodies on underground waters.
- I. Changes of ground-water levels.
  - 1. Changes due to variation of level of surface streams receiving ground-water discharge.
  - 2. Changes due to movements away from surface water bodies.
- II. Variations of pressure on confined waters.
  - 1. Changes due to communication between surface and underground water bodies through intervening beds.
    - a. Communication through joints and other passages.
    - b. Communication through the body of the intervening beds.
  - 2. Changes due to transmission of pressure through intervening beds.
  - 3. Changes due to plastic deformation.

It is calculated that a very slight movement from the water of surface bodies on the ground water table is sufficient to produce a pronounced rise in the waters of wells. Considering an area 1,000 feet square, a downward water movement of only one-thousandth of an inch through the overlying confining strata would be equivalent to a rise

[1] U. S. Geol. Survey Bulletin 319, p. 31–2.

of approximately 25 feet in a single well, or one foot in 25 wells. The transmission of pressure through the so-called impervious strata may sometimes be a factor of artesian head, even though no movement of water takes place.

The influence of the pressure of the local ground-water table on the artesian head appears to be well illustrated by the profiles of artesian heads of the La Crosse, Kickapoo, and Baraboo rivers, Figures 10, 11 and 12.

The head of the flowing artesian wells at Waupun at 886 feet and at Beaver Dam at 889 feet is at least 100 feet higher than the effective artesian head obtained by artesian wells along the Fox river valley lying to the west in the direction of the courses of the movement of the artesian water confined to the Potsdam aquifers.

Areas of maximum artesian head.—The important influence of the groundwater table on the artesian pressure appears to be well illustrated in many parts of the state, and it is only by recognizing this influence that the relatively high heads attained by many of the flowing wells can be explained. In general, therefore, the artesian pressure in areas of high groundwater tables on the inter-stream divides is much greater than the pressure in the valleys, though it is only in the valleys that artesian flows above the surface can be obtained. The contours of equal artesian pressure shown on the map (Plate 1) conform in a general way to the contours of the groundwater table, and since the latter conforms in a general way to the contours of the land surface the artesian contours are found to approximate the topographic contours. Areas of maximum artesian head occur in various parts of the state and these areas conform to the areas of maximum altitude of land surface and groundwater level. The areas of maximum artesian head are located on the inter-stream divides between the major drainage lines of the state, and as shown by blue lines on the geologic map are as follows:

1. Area of maximum artesian head on the divide between the Chippewa and St. Croix rivers.
2. Area of maximum artesian head on the divide between the Chippewa and Black rivers.
3. Area of maximum artesian head on the divide between the Black and Wisconsin rivers.
4. Area of maximum artesian head on the divide between the Wisconsin and lower Rock rivers. (Southwestern Wisconsin).
5. An area of maximum artesian head on the divide between the Fox and the upper Rock rivers. (East-Central Wisconsin).

Some Problems Relating to Artesian Well Supplies

Experiences at Madison, Wisconsin, Rockford, Illinois, and Joliet, Illinois, prove conclusively that in favorable localities artesian supplies of 6,000,000 to 10,000,000 gallons per day may be pumped by installing the proper pumping systems. However, where the artesian head stands considerably below the surface, no such quantities of water will be obtainable. For the ordinary city or village one artesian well is sufficient, but if it becomes necessary to drill more, it is advisable to so place the wells that they shall receive the least possible interference from one another. In all cases the wells should be located on a line at right angles to the direction of the underground flow, and at least 1,000 to 1,500 feet from one another. If the wells are to be heavily pumped this distance should be increased. On the whole it is easier to increase the supply by pumping the water from lower levels in the well, but in those localities where few artesian wells have been drilled and where the interference will be a minimum, it may be considerably cheaper to drill new wells to increase the supply. Much depends upon local circumstances as to which one of the methods should be used,—in some places the first, in others the second, would be more economical.

Yields of Wells.—As pointed out by Slichter,[1] the conditions affecting the amount of ground water available for wells are: (1) Magnitude of the area contributary to the wells; (2) amount of the rainfall upon this area; (3) geologic structure, such as (a) the arrangement of stratification of the material, (b) the breadth and depth of the water-bearing medium, and (c) the character or composition of this material such as its fineness and porosity; and (4) physiographic features of the land surface, such as mountains, plateaus, hills, valley, plains, forests, prairies, cultivated areas, etc.

The yield of an artesian well depends on the preceding factors, and especially upon frictional resistance which the water encounters in flowing through the drill hole or casing of the wall. This frictional resistance to the flow depends upon the length and the diameter of the casing. Formulae for determining the discharge under varying conditions are given by Slichter in the publication cited, in which the effect of friction in the pores of the transmitting medium outside the well is also considered. Because of the lack of accurate knowledge of the exact nature of the water-bearing bed and other factors affecting the flow, the computation of yields is less satisfactory than actual mea-

[1] Water-supply and Irrigation Paper, U. S. Geol. Surv. No. 67, pp. 73, 83.

surements. Such measurements can be made by the aid of a foot rule, it simply being necessary to measure the height of a jet and the diameter of a pipe in the case of vertical casings, or the amount of drop of horizontal jets in a fixed distance. On pages 90 to 93, in the publication already quoted, Professor Slichter has given tables for use in such computations of flow.

Character and arrangement of wells.—If several wells are drilled, they should be arranged as nearly as possible at right angles to the general trend of the water and inclination of the water-bearing strata, so that the largest amount of water may find its way readily into the tubes or collecting pipes. In any locality where the number of wells has caused an overdraft, or where an overdraft is feared, it will be advisable to place the wells as far apart as possible. Wherever the water is obtained from flowing wells, the distance between the wells may very well be as great as the cost of piping and the contour of the country permits. Where the water is pumped, from either flowing or non-flowing artesian wells, the extra cost of separate pumping stations will usually prevent the distant separation of the wells. The mutual interference of wells will limit the number in the vicinity of the station, and the air leakage in long suction pipes, which greatly reduces the vacuum at the pumps, will prevent the locating of the wells more than several thousand feet from any given pumping station.

The cause of the rapid decrease in pressures and available supply of water in the localities where a large number of wells have been put down, must be sought in the supply obtainable from the water-bearing beds themselves. The flow of water through porous beds depends upon the size of the pore space and size of grain. The coarser the sand, the greater the amount of water which may get to any particular well. The amount of water that can enter the local reservoir depends upon the ease with which the water is transmitted through the porous beds. The most favorably situated wells get the greatest supply. One of the potent factors to consider is the height of the water level in the well. Other factors being equal, the well that is most heavily pumped, will receive the greatest supply, the rate of increase being nearly proportional to the decrease in pressure due to lowering the head.

Interference of Wells.—Sometimes the amount of water in a porous bed is not equal to the quantity in demand. This condition often developes where a new well is sunk near an old one and only a small increase in the amount of water is obtained. In this case, the water is divided between the two wells, and they are said to interfere. The interference of wells depends upon many factors and no definite statement can be

made as to the distance within which wells interfere unless a concrete case is taken. The condition of porous beds, the position of wells with respect to the direction of underground flow, the head at which the water in the well is to be pumped, all tend to modify the results. Where the heads in the wells under pumpage remained the same, the interference with other wells 1,000 feet away and located at right angles to the direction of flow may not be noticeable. But as soon as one well is pumped much harder than the others and the head greatly reduced, its sphere of interference will be greatly extended. In wells located parallel to the direction of the flow, they usually interfere with one another within a distance of several miles.

Friction tends to prevent one well from obtaining the entire supply from an artesian basin. The extent to which friction is effective depends upon the texture, and thickness of the porous beds. The possibility of a well's decrease in flow due to the clogging of it's pore space near the well must also be considered. Special experimentation is required to demonstrate that loss of head or flow is due to this cause, but that some wells are so affected is certain, as was pointed out by Slichter[1] in the case of the Savannah wells.

Causes of Decrease in Flows.—In the case of old wells and sometimes of new wells, where the flow has greatly diminished or ceased entirely, the decrease may not be due to a diminished supply in the artesian reservoir. Before any remedy to increase the flow can be suggested the special cause of the decrease must be known.

Leakage commonly due to corroded pipes is a common cause of a decrease in the flow. In some wells the iron pipes have been corroded within a period of two to five years and the artesian flow completely destroyed. Cast iron and galvanized pipe last considerably longer than iron pipe.

The water may escape through the openings, or the enlarging of the crevices in the rock where the well was left uncased. The well may have become partly filled with sand and clay and the flow thereby decreased, or the casing itself may become partly clogged with detritus thereby shutting off the yield. The tubing or packing may have been insecurely placed, allowing the water to leak back into the natural subterranean water-ways. Old neglected wells in the vicinity, and in places there are many, may have their pipes corroded and thus allow the water to escape, thereby reducing the artesian pressure of the entire locality. New wells at lower levels, as in Germantown, Wisconsin, destroy the heads at the older wells by allowing the waters free escape.

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[1] Water-supply and Irrigation Paper No. 67, C. S. Slichter, pp. 95–101.

In places, it appears also, that the pore space of the water-bearing strata becomes partially filled, either through mechanical means or by organic growths.

Many other factors and unfavorable conditions may develope tending to decrease the head or lessen the flow. Any one of these or any combination of them may bring about the destruction of the flow of a well, and more or less decrease the efficiency of a local artesian district. In order to apply the most satisfactory remedy for increasing the flow, it is necessary to have a complete record of the underground conditions by which to direct the work.

Methods of Increasing Supply of Wells:—The flow of water into a well may be increased by torpedoing the water-bearing stratum, thereby opening more crevices through which the water may flow into the well. This has been tried in several cases with marked success, and has been employed in shallow wells, e. g. the creamery well, at Wittenberg, with remarkable results. This method might be resorted to if the crevices or pores of the strata became filled near the wells either by mechanical filling or through the growth of Crenothrix or other plant and bacterial growths.

In some localities, the discharge of artesian wells may be greatly increased by the use of deep-well pumps. The lower the head of water in any given well is reduced, the greater will be the amount of water available. The increase in discharge is not directly proportional to the amount of lowering but lags somewhat behind. In the case of the Madison wells, lowering the water in the well 18 feet furnished an increase of about 500,000 gallons per 24 hours, and a drop of 72 feet increased the capacity to 1,500,000 gallons in 24 hours. In this case the capacity increased about three-fourths as much as the head decreased. There are, however, not a sufficient number of tests at hand to warrant any definite conclusion, and since the conditions of the strata and pore space, as well as the friction at the different wells varies greatly, it is to be expected that conditions at no two wells will be axactly the same.

Contamination of Groundwater Supplies

Most people living in villages and in the rural districts rely upon wells from which to obtain their water supply. Open wells are commonly 3 to 5 feet in diameter and from 15 to 30 feet deep, though in many instances, open dug wells are from 50 to 100 feet deep. They are generally walled up with stone or brick, though not infrequently boards, planks and logs are used. The water seeps into most open wells and the depth is determined by the general water level of the locality.

Contamination of Open Wells.—Open wells are subject to contamination both from above and below the ground. The usual protection of the wells above is a board platform, in which cracks are soon developed by constant wetting, warping and shrinkage. The drippings from the pump upon the platform, wash down into the well whatever accumulations there are of dirt from shoes, domestic fowls, and other sources.

Many open wells are polluted from below the surface. The seepage from cess-pools and the drainage from manure piles enters the ground and becomes a part of the body of underground water upon which the wells depend.

Drilled and Driven Wells.—In recent years drilled wells have gradually supplanted the old type of open dug wells. Drilled wells are not only cheaper to make than dug wells, but they are also usually more sanitary.

Drilled wells are made by first drilling a hole and then driving a pipe into it. The drilled wells in rural districts generally range in diameter from 4 to 8 inches, and usually go to a depth of 100 feet or more, depending upon the depth of the groundwater level.

Driven wells are those which are made by driving a pipe, provided with a well point, into the loose surface deposits. They can be sunk only in unconsolidated material, such as valley alluvium or gravelly and sandy glacial drift. The pipes are generally from 2 to 4 inches in diameter, and the wells usually vary in depth from 20 to 40 feet, though in some localities they are driven to much greater depths.

Pollution of Farm Wells, Springs, and Cisterns.

Farms, which are generally remote from towns and cities or other areas of congested population, are especially favorably situated for obtaining pure and wholesome water. As a matter of fact, however, polluted water is exceedingly common on the farms, and typhoid fever, generally contracted from drinking water, is usually more prevalent in country districts than in cities.

Many of the failures to protect water supplies used for drinking are due to a lack of knowledge of the manner in which waters circulate through the ground, and of the ways in which the ground water may become polluted. The diagram, fig. 8, illustrates the location of safe and unsafe wells, and the general relation of these to the location of farm buildings and to the ground water level.

Springs may also be contaminated, especially the seepage springs, if proper care is not taken in the location of buildings near the spring.

Open or dug wells may be polluted by material seeping through the ground and the curbing or entering from the top of the well.

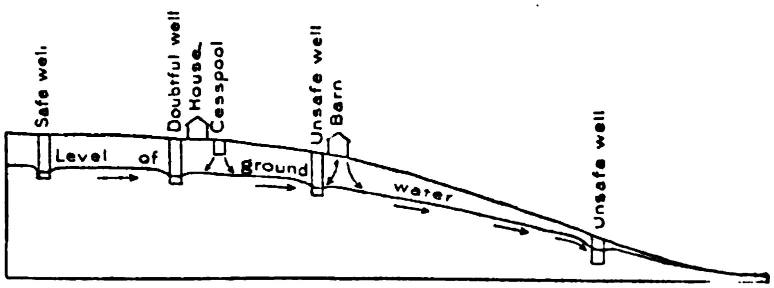


Fig. 8.—Diagram showing location of safe and unsafe wells and their relation to farm buildings.

The distance from a source of pollution, such as cesspools and barnyards, at which a surface or open well may be sunk with a fair degree of safety varies with the formation, but generally should never be less than 100 feet and often should be at least 200 feet. The more open and porous the soil and the more rapid the movement of the ground water, the greater is the safety distance required. Well waters that become

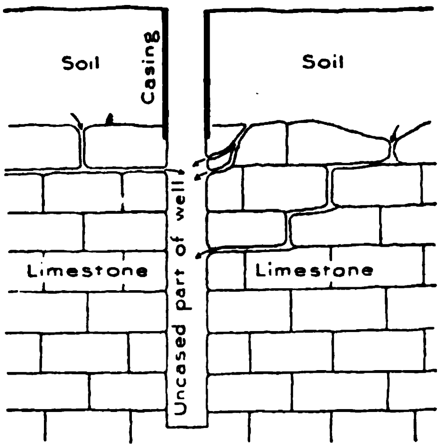


Fig. 9.—Diagram showing danger of pollution where casing is carried only to rock.

muddy after rain storms indicate surface contamination and should be avoided if possible. Wells should be protected from surface water by properly constructed curbing, stock should be kept away from the well, and protection from pump drippings, from small animals, and from dust should be ensured, as they are all possible sources of pollution.

The waters of deep wells are usually safe and hence many people go to the expense of drilling for deep well water. Deep wells, may however become polluted by the entrance of surface waters (See fig. 9) unless the casing is carried into the well a sufficient depth to shut off all surface water entering through fissures.

Cisterns, which are especially valuable in supplying soft rain water or in furnishing supplementary supplies from wells, if properly constructed, are safe sources of water supply. The disadvantage of cisterns is the liability of contamination by dust from the roof, and the liability to crack and admit shallow and possibly polluted waters.

CHAPTER III.

THE FLOWING ARTESIAN WELLS OF WISCONSIN

While flowing artesian wells occur to some extent over the entire state most of them are located within the area underlain by the Paleozoic rocks, as shown on the accompanying geologic map. (Pl. I in pocket). A small number of flowing artesian wells in the surface formation occur along the shore of Lake Superior. Only a few flowing artesian wells have been found in the crystalline district, and these are due to very local conditions. (See pp. 85–7).

The water horizons in the Paleozoic rocks lie deeper and deeper as the distance increases from the outcrop of crystalline rocks of northern Wisconsin, but the inclination of the strata is so gentle that in the southern part of the state, the bottom of the lowest water horizon, the Upper Cambrian (Potsdam) sandstone, is rarely more than 2,200 to 2,500 feet below the surface. The entire water-bearing strata down to the impervious granite may, therefore, be easily penetrated by the well drills.

While all the water horizons of the state give rise to artesian wells, they may not do so in every locality where they occur. The conditions favorable for obtaining artesian waters from formations overlying the Potsdam sandstone, are usually found only in eastern Wisconsin, south of Green Bay. The artesian wells, with source in the Potsdam sandstone, are found over all the Paleozoic area except near the edge of its outcrop adjacent to the area of the crystalline rocks, and in the Kewaunee-Door Peninsula east of Green Bay.

Flowing Artesian Wells from the St. Peter and the Upper Cambrian (Potsdam) Sandstone.

While artesian areas, with source of flow in the Upper Cambrian (Potsdam) and St. Peter sandstones, are confined, in a general way, to areas of relatively low altitude, yet there is a considerable range in the altitudes of the artesian heads, not only over the entire state, but

also over each individual district of flowing wells. The areas of flowing wells are within the river valleys and along the shores of Lake Michigan and Green Bay. In the following descriptions of the flowing wells from the sandstone group, the districts of flowing wells along the rivers and lakes are first considered, followed by a description of the artesian conditions along the shores of Lake Michigan and Green Bay.

Flowing Artesian Wells Along the Mississippi River Valley.

The water confined within the Upper Cambrian sandstone aquifer is very generally under sufficient pressure to produce artesian flows along the Mississippi river from the vicinity, a short distance north of Minneapolis, Minn. to St. Louis, Mo., the maximum head above the river probably being obtained somewhere near Dubuque where a head of 153 feet above the river has been recorded. The head of the flowing artesian wells along the Mississippi river bordering Wisconsin is shown in the following table:

Table 7.—*Maximum initial head*[1] *of flowing wells in the Mississippi Valley, north to south.*

City.	Owner.	Head above sea level. Feet.	Head above river, low-water. Feet.	Head above curb. Feet.
Hastings, Minn	C. M. & St. P. R. R.	724	53	14
Red Wing, Minn	C. M. & St. P. R. R.	760	90	75
Maiden Rock, Wis	Maiden Rock L Co.	709	44	34
Fountain City, Wis	City Well	690	46	20
Winona, Minn	City Well	686	49	20
Onalaska, Wis	City Well	664	34	5
La Crosse, Wis	C. B. & Q. R. R.	659	31	12
Stoddard, Wis	H. H. White	706	86	60
Genoa, Wis	John Franzen	692	75	25
De Soto, Wis	Peter Loftus	661	47	21
Prairie du Chien, Wis	Stock Co.	704	100	59
McGregor, Iowa	City Well	694	87	62
Cassville, Wis	City Well	658	41	16
Dubuque, Iowa	Butcher's Ass'n	740	153	133

[1] All figures referring to head in the following tables are given in feet.

The present head at many of the wells cited is much below that given in the table as the *maximum initial head,* on account of local interference of the many wells drilled in the same locality, and in many instances loss of pressure due to leakage from corroding of the casing developed since the well was first drilled. At Red Wing the present strongest head is about 30 to 40 feet above the river whereas the maximum initial head was 90 feet above the river level. At Maiden Rock, the well was only recently drilled, in 1912, and the maximum initial

head is still maintained. At Prairie du Chien, the well cited was drilled in 1875, and the present head is only a few feet above the surface, though the well at McGregor, Iowa, is reported to have as strong a pressure as originally. At Dubuque, the present maximum head is probably between 80 and 100 feet above the river level in wells properly cased and protected.

Flowing Artesian Wells in Valleys Tributary to the Mississippi River

Certain sections of many of the river valleys, tributary to the Mississippi, are favorable for the development of flowing artesian wells. The artesian water is confined to the Upper Cambrian sandstone formations in typical artesian slopes, the artesian heads declining relatively rapidly though very generally with increasing height above the river, in going down the valley. (For definition of artesian slope see page 49).

Chippewa Valley.—The maximum initial head of the flowing artesian wells in the lower course of the Chippewa Valley is shown in the following table:

Table S.—*Maximum inital head of wells in the Chippewa Valley.*

City.	Head above sea level.	Head above river.	Remarks.
Meridean	741	11	Head 5 feet below curb.
Durand	751	48	Prindle's Inn. Head 28 feet above curb.
At mouth of Chippewa river	710 to 730	40 to 60	Head inferred at 40 to 60 feet above river level.

The only flowing wells known along the Chippewa river are located at Durand, where a head of 48 feet above the river has been obtained. At Meridean, 13 miles farther up the river, a well drilled to the granite failed to flow, although the water rose in the tube some distance above the local groundwater level, within 5 feet of the surface. The flowing wells in Durand are located at the base of a high bluff, and it seems quite probable, that the artesian pressure in this situation is reinforced by the pressure of the underground water in the adjacent bluffs, while the non-flowing well at Meridean is located farther out in the valley, several miles from high bluffs.

The chances for finding flows along the Chippewa river, above the mouth of the Red Cedar river, are not very good because the river and

adjoining low bottoms on which the flows would have to be located, are situated near the middle of the old filled valley and some distance from the bluffs, thus furnishing opportunities for leakage of the artesian water into the old valley, besides the loss of favorable conditions for reinforcement of the artesian pressure due to a high ground-water table in the adjacent uplands.

South of Durand, no artesian flows are known, but the chances for obtaining flows from 30 to 50 feet above the river, are good, especially along the western side of the river where the low ground of the river bottoms is close to the high bluffs. On the other hand, where the low ground of the river bottom is some distance from the bluffs, for reasons above stated, the chances for obtaining flows are not so favorable.

Red Cedar Valley.—At Menominee, Dunn County, located on the Red Cedar river, a large tributary of the Chippewa, the city wells drilled to the granite flowed about 10 feet above the surface, or about 30 feet above the river, when first drilled. The flow was not sufficient for the city supply and the wells are pumped. The Red Cedar flows in a narrow rock-bound valley from Menominee to Dunnville, and throughout this stretch of the valley the prospects for obtaining artesian flows, with head from 10 to 30 feet above the river, are fair.

Beef (Buffalo) Valley.—In 1912 only two flowing wells, were known to be along the Beef river, namely one far up the valley at Mondovi, with original head of 6 feet above the surface, and one 3 miles above the mouth of the river, with head about 24 feet above the level of the river. The flowing well at Mondovi is 418 feet deep, drilled to the granite, striking the sandstone at depth of 80 feet, with 10 in. casing to depth of 90 feet. The altitude of the curb is not known but is probably near that of the railroad station which is 738 feet. From our knowledge of artesian flows along the Chippewa river to the north, and along the Trempealeau river to the south, it seems reasonable to predict the probable development of artesian flows at various places along the valley. If a profile of the Beef river were available it would be possible to predict what sections of the valley are likely to be productive of flows.

Since the above was written and sent to the press information has been obtained of the drilling of a number of flowing artesian wells in 1913 and 1914 in the Beef valley, from the vicinity of Mondovi up to Eleva and Strum. The artesian wells are generally drilled down to the granite and usually have a head 5 to 15 feet above the valley bottoms. See also the local description of Buffalo and Trempealeau counties.

Trempealeau Valley.—Flowing wells occur in the Trempealeau valley as far up the river as Whitehall, as indicated in the following table:

TABLE 9.—*Maximum head of flowing wells in the Trempealeau Valley.*

City.	Head above sea level.	Head above curb.	Remarks.
Whitehall	790	12	
Arcadia	740	12	Head at Winona 40 feet above Mississippi river.
At mouth of river	686	....	

The head, from Whitehall to the mouth of the river, declines from about 790 feet to 686 feet. While no flows are known to occur between Arcadia and Winona, at least a part of this stretch of the valley, appears to be favorable for the development of flowing artesian wells. Flowing wells might be developed above Whitehall, though any prediction would have to be based on data, which is not available, showing the relation of the artesian profile to the river profile.

Black River Valley.—No flowing wells are known to occur in the Black River valley except those reported at Galesville in the tributary Beaver Creek valley. However, the prospects appear to be good for the development of flows on low ground adjacent to the river, possibly as far up the valley as Melrose, but probably not beyond.

La Crosse Valley.—Flowing wells along the La Crosse river are developed only in the vicinity of Leon and Sparta, the area of flowing wells extending from Rockland as far up the La Crosse river as 2 miles east of Trout Falls, 11 miles east of Sparta, and up the Little La Crosse as far as Melvina. The approximate head of the flowing wells in the vicinity of Sparta and at La Crosse is indicated in the following table:

TABLE 10.—*Maximum initial head of artesian wells in the La Crosse Valley.*

Location.	Head above sea level.	Head above (+) or below (−) surface.	Remarks.
Frank Rawlu's farm.	870	+ 8	Head about 30 ft. above river.
Trout Falls	850	+10	Head about 20 ft. above river.
Angelo	834	+14	Head about 40 ft. above river.
Sparta	811	+18	Head about 40 ft. above river.
Rockland	764	+ 7	Head about 20 ft. above river.
Bangor	735	−10	Head 10 ft. below surface.
West Salem	720	−25	Head 25—20 ft. below surface.
La Crosse	659	+12	Head 30 ft. above Mississippi river.

The decline in the head, from the highest points up the valley down to Rockland, is estimated to be about 100 feet in a distance of about 15 miles, the initial maximum heads generally being 10 to 20 feet above lowest ground along the river adjacent. Probably 200 to 300 flowing wells have been obtained in this productive area. Below Rockland, no artesian flows have been obtained, though attempts have been made at various places along the river at Bangor and West Salem. The lack of favorable conditions for artesian flows from West Salem to Rockland, is apparently, on account of the flat slope of the valley from Rockland down to West Salem.

The La Crosse river may be divided into three parts: 1st, The upper end of the valley, with a steep slope from the head waters down to the vicinity of Rockland, the fall between Melvina on the Little La Crosse to the vicinity of Rockland being over 120 feet in a distance of about 12 miles, or 10 feet per mile, and the fall from Trout Falls to Rockland being about the same amount in about 15 miles, or 8 feet per mile; 2nd, The middle part of the valley, with a very gentle slope from Rockland down to West Salem, with a fall of only about 20 feet in 10 miles, or about 2 feet per mile; and 3rd, The lower end of the valley, with a relatively steep slope from West Salem down to the Mississippi river, with a fall of 60 or 70 feet in 10 miles, about 6 or 7 feet per mile.

If the hydraulic gradient within the flowing artesian area above Rockland, which is approximately the same gradient as the valley slope, 8 to 10 feet per mile, be maintained below Rockland, the artesian head would necessarily soon fall below the surface of the valley below Rockland, in the very gently sloping stretch of the river between Rockland and West Salem. If a hydraulic gradient closely approximating 5 feet per mile, be maintained between Rockland and La Crosse, as indicated by the available head at Rockland, about 764 feet, and at La Crosse, about 660 feet, a decline of 96 feet in 20 miles, the artesian head would also necessarily fall below the level of the river on account of the slight fall of the valley bottom between Rockland and West Salem. A 5-foot hydraulic gradient, in fact, appears to approximate between Rockland and the mouth of the river, as indicated by the available head at West Salem at 710 to 720 feet, about 25 below the surface. Somewhere below West Salem, therefore, in the steep lower course of the river, the artesian head would rise above the level of the valley, reaching to 30 feet above, as at Onalaska and La Crosse. The relative positions of the valley gradient and the hydraulic gradient in the La Crosse valley are shown in the accompanying section, Fig. 10.

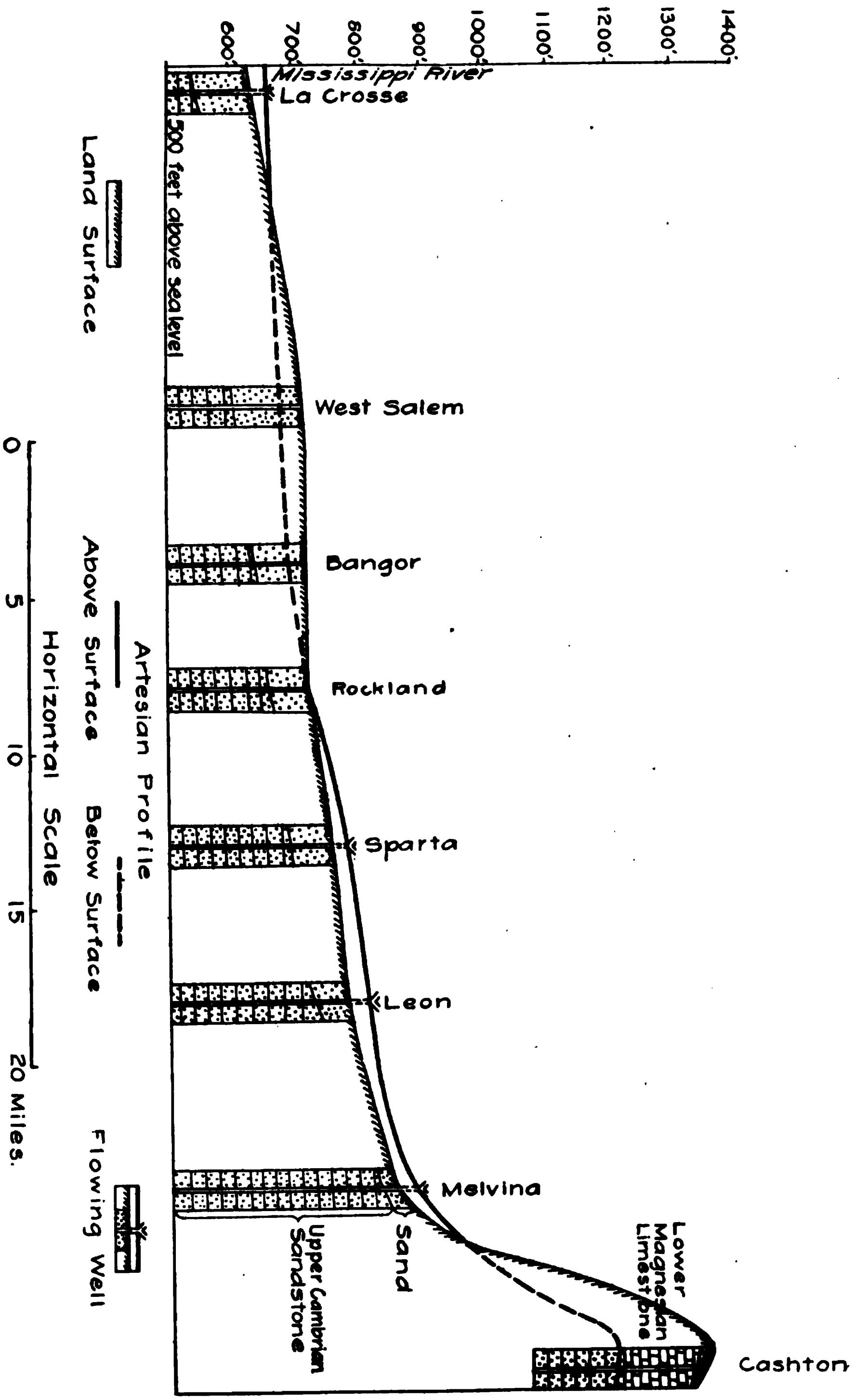


FIG. 10.—SECTION SHOWING THE RELATION OF THE ARTESIAN PROFILE TO THE SURFACE OF THE LA CROSSE VALLEY.

Coon Creek Valley.—Flowing wells along the Coon Creek valley, are developed at Chaseburg and Coon Valley, with approximate heads as indicated in the following table:

TABLE II.—*Maximum initial head of flowing wells in Coon Creek Valley.*

Location.	Head above sea level.	Head above surface.
Coon Valley	About 780	32
Chaseburg	About 780	30
Stoddard	706	60

Flowing wells occur as far up the valley as 3 miles east of the village of Coon Valley, at the farm of Rev. Rualkamm, where a head of 14 feet above the surface is obtained. In the village of Coon Valley, are 5 flowing wells, from 450 to 500 feet deep, each cased about 300 feet to the shale or "soapstone." Conditions appear to be favorable for obtaining artesian flows 6 or 8 miles east of the village of Coon Valley, up to an altitude of 850 to 900 feet on low ground adjacent to the creek. Springs are abundant along the valley sides above altitudes of 900 to 950 feet, the highest springs at the source of Coon Creek being at elevation of about 1100 feet.

At Chaseburg, are several strong flowing wells, the pressure of one being utilized to operate a small motor plant at the Geo. Carson blacksmith shop, and the pressure of another is used to operate a hydraulic ram which supplies water to farmhouses in the vicinity. The wells at Chaseburg are about the same depth as those at Coon Valley.

At Stoddard are several flowing wells, ranging from 400 to 500 feet deep, cased about 130 feet, having heads of 50 to 60 feet above the surface. Two of these flowing wells are utilized for the development of power.

Kickapoo Valley.—Artesian flowing wells are located at the lower end of the Kickapoo valley, and also in the upper half, but none are known along a considerable portion in the lower middle part. The maximum initial heads at various points in the valley are shown in the following table:

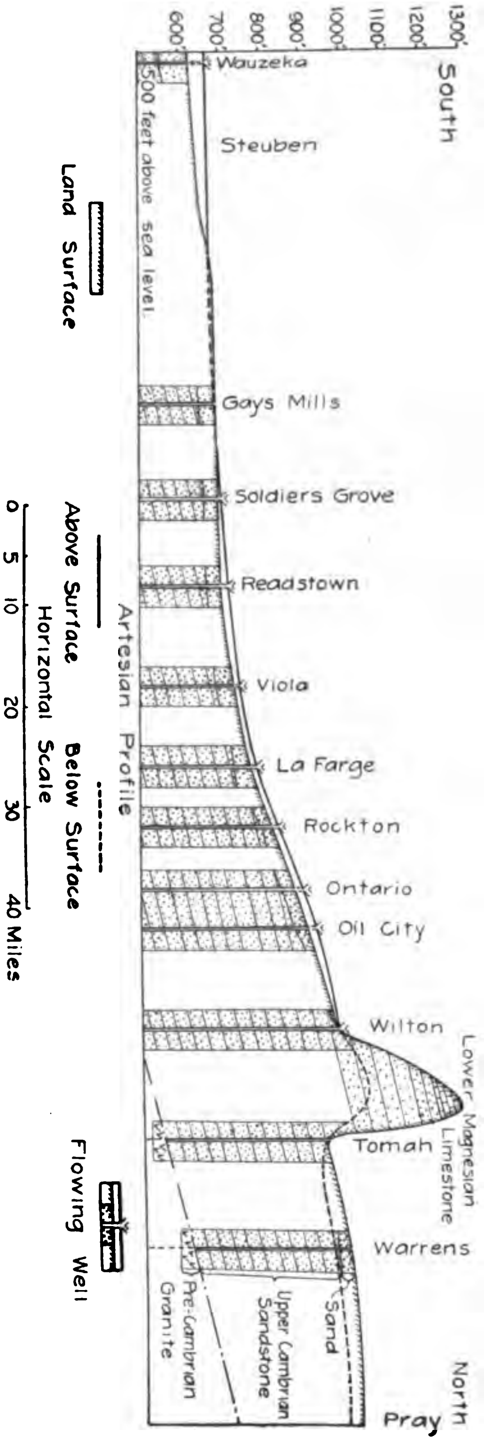


FIG. 11.—SECTION SHOWING THE RELATION OF THE ARTESIAN PROFILE TO THE SURFACE OF THE KICKAPOO VALLEY.

TABLE 12.—*Maximum initial head of flowing wells in Kickapoo Valley.*

City.	Head above sea level.	Head above river.	Head above curb.
Wilton (3 miles north of)	About 991	....	2
Oil City	" 920	29	25
Ontario	" 880	....	10
Rockton	" 890	....	32
La Farge	" 795	19	16
Viola	" 755	....	4 to 6
Readstown	" 730	....	?
Soldiers Grove	" 720	....	?
Wauzeka	688	55	34

The highest head of a flowing well from the Potsdam aquifer in Wisconsin, thus far recorded, appears to be in the upper part of the Kickapoo valley, 3 miles north of Wilton, at an elevation of 991 feet above sea level. From the vicinity of Wilton to La Farge, the valley declines nearly 200 feet in about 25 miles, establishing a gradient of about 8 feet per mile. From La Farge to Viola the valley slope is about 4 feet per mile. From Viola to the mouth of the river, near Wauzeka, the slope of the valley is only 2 to 3 feet per mile, falling about 110 feet in about 45 miles. See the cross section, Fig. 11.

The flowing wells along the Kickapoo valley, occur at Wauzeka, at the lower end of the valley, and from Soldiers Grove, near the middle portion, up to Wilton, with heads as indicated in the table. The artesian gradient from Wilton to La Farge, closely approximates the valley slope of about 8 feet per mile. Below La Farge, at the Robinson farm above Readstown, and at Soldiers Grove, the altitude of the artesian head is not known, but the head very probably declines more slowly than in the section of the valley above La Farge. The high artesian head at Wauzeka, 34 feet above the curb and 55 feet above the river, seems to indicate the probability of favorable conditions for artesian flows throughout the gentle slope of this valley between Soldiers Grove and Wauzeka though none are now known to occur between these points. Favorable conditions for flows should occur at least as far up the valley as Barnum.

Baraboo Valley.—Flowing wells from the Upper Cambrian (Potsdam) sandstone, the artesian pressure, reinforced to a variable extent by the favorable character of the valley deposits, occur along the Baraboo river, from Elroy to Baraboo, as indicated in the following table:

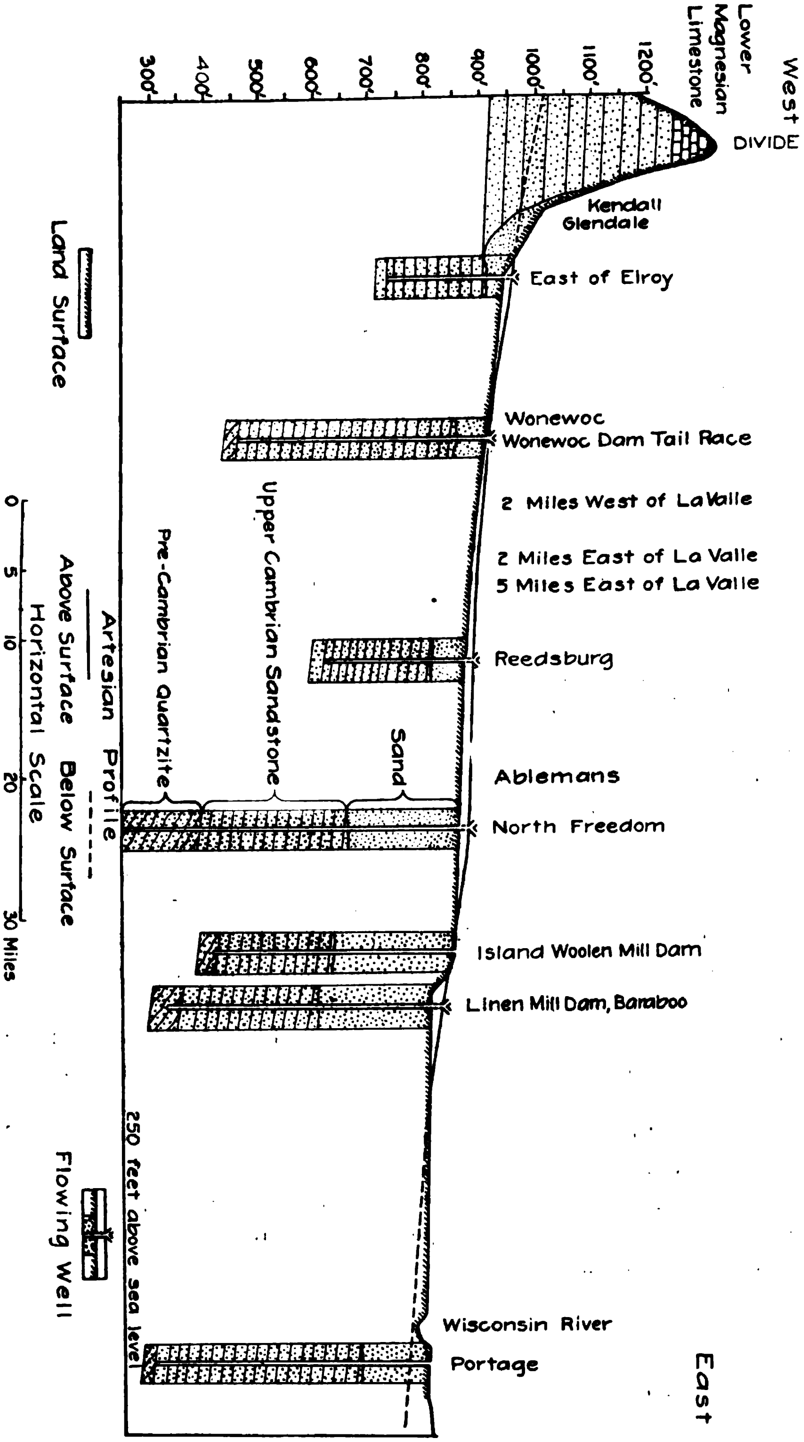


FIG. 12.—SECTION SHOWING THE RELATION OF THE ARTESIAN PROFILE TO THE SURFACE OF THE BARABOO VALLEY.

TABLE 13.—*Maximum initial head of flowing wells in Baraboo Valley.*

City.	Head above sea level.	Head above river.	Remarks.
Elroy	950	12	
Wonewoc	910	2	Head 2 ft. above crest of dam.
Reedsburg	876	12	Head about 12 ft. above river below dam.
Ableman	870	15	
North Freedom	860	15	
Baraboo	830	15	Head about 15 ft. above crest of waterworks dam.

The artesian head declines from an altitude of about 950 feet at Elroy, to about 830 feet at Baraboo, a fall of 120 feet in about 40 miles, as the railroad runs, indicating an average artesian gradient of 3 feet per mile, approximately the same as the valley gradient.

Artesian flows have been developed in exploring for iron ores several miles below Baraboo, but they are not likely to be developed far down the river, not beyond the Lower Narrows, on account of the very gentle slope of this part of the valley, the descent of the river, below Baraboo, being only 13.7 feet in 24 miles, an average fall of only 0.6 feet per mile, as compared with a valley slope and artesian slope of 3 feet per mile above Baraboo. The relation of the valley gradient to the artesian gradient, along the Baraboo river, is shown in the accompanying section, Fig. 12.

Within the past two or three years, since 1911, the flowing wells in the vicinity of North Freedom, within one or two miles of the Oliver Iron mine, have ceased flowing, on account of the continuous pumping of water at the mine. Appreciable lowering of the artesian head in the village of North Freedom is reported, but no influence on the head of the flowing wells at Ablemens is noticeable. Should the pumping at the mine cease, the former artesian head will be regained.

Rock River Valley.—Flowing artesian wells from the Potsdam aquifers, as well as from the overlying surface formations, are found along the valley throughout the entire course of the Rock river in Wisconsin, as well as in Illinois. The highest heads, above sea level, are found near the source of the head water streams, as at Waupun, Beaver Dam, Madison, and Whitewater, from which points, the artesian gradient declines down through the main valley of the river. The approximate maximum initial heads at various points in the Rock river valley are indicated in the following table:

TABLE 14.—*Maximum initial head of flowing artesian wells in the Rock River valley and tributary valleys, north to south.*

City.	Name of valley.	Head above sea level.	Head above surface.
Beaver Dam	Beaver Dam	886	About 16 ft. above Beaver Dam Lake.
Waupun	Rock River (West Branch)	883	Present head 879, only a few feet above river.
Horicon	Rock River	860	Only a few feet above river.
Madison	Yahara River	863	About 4 feet above Lake Mendota.
Stoughton	Yahara River	848	Only a few feet above river.
Watertown	Rock River	883	About 15 feet above crest of upper dam.
Cambridge	Koshkonong Creek	840	About 6 feet above curb.
Waterloo	Waterloo Creek	835	About 9 feet above curb.
Whitewater	Whitewater Creek	839	About 19 feet above curb.
Jefferson	Rock River	823	About 29 feet above curb.
Fort Atkinson	Rock River	808	About 28 feet above river.
Edgerton	Rock River	833	About 45 feet above river.
Janesville	Rock River	802	About 40 feet above crest of Monterey dam.
Rockford, Ill	Rock River	744	About 44 feet above river.

The decline in the artesian heads down the valley of the Rock, in a general way, is about 1 to 2 feet per mile, not only along the main valley but also along the tributary valleys. The relatively high head at Edgerton, at approximately the same altitude as at Watertown, Waterloo, and Whitewater, is probably explained by the fact that Edgerton, though located on the present course of the Rock river, is really some distance from, and therefore outside the old pre-glacial valley of the Rock river. This pre-glacial[1] valley, now filled with sand and gravel to a great depth, extends directly south from Fort Atkinson, and is about 6 miles east of Edgerton and very near to Janesville and Beloit. The bottom of the old valley lies about 300 feet below the present level of the Rock River between Ft. Atkinson and Beloit, and it is probably on account of leakage of the artesian waters into this old valley, that the heads of artesian wells outside the old valley are relatively higher than those within or near to the old valley.

It is of interest to note that the artesian head at Whitewater east of the Rock river, is approximately the same as it is at Waterloo and at Cambridge on the west side of the river, showing, therefore, no apparent decline in the hydraulic gradient, in following eastward down the dip of the Upper Cambrian sandstone, and in increasing the distance from the area of outcrop. The artesian head of the Potsdam water on the east side of the Rock river valley, is probably maintained by the influence of the local groundwater level in the upland divide, between the Rock river and the Lake Michigan drainage systems.

[1] See W. C. Alden, Professional Paper No. 34, U. S. Geol. Survey, Pl. II.

Fox River Valley (of Ill.).—The Fox River of Illinois rises in northwestern Waukesha county, and flows southward through the western parts of Racine and Kenosha counties. Flowing artesian wells are known along this valley in the vicinity of Mukwanago, and at Burlington, and farther south in Illinois, at Elgin and Aurora, as indicated in the following table:

TABLE 15.—*Maximum initial head of artesian wells in the Fox River Valley (of Illinois).*

City.	Head above sea level.	Head above surface.
Mukwanago, Wis.	830	About 15 feet.
Burlington, Wis.	795	About 30 feet.
Elgin, Ill.	739	About 24 feet.
Aurora, Ill.	710	About 60 feet.

The decline of 35 feet in the artesian head, from Mukwanago to Burlington, indicates an artesian gradient of about 2 feet per mile in the upper section of the river, while the decline from Burlington to Elgin, and to Aurora, indicates an average gradient of much less than one foot per mile.

Judging from the altitude of the artesian head at Mukwanago, of 830 feet, as well as that of the strongest flow in Milwaukee, at altitudes of about 790 feet, artesian flows from the Upper Cambrian sandstone should be obtainable on low ground along the Fox river in the city of Waukesha at altitude of 800 to 810 feet. However, while artesian flows have been obtained in Waukesha from the Niagara limestone, the head of the water in the sandstone. in one well drilled to depth of 1,500 feet was reported to have been as low as 60 feet below the curb. The failure to obtain a flow from the sandstone in Waukesha may be due to some unfavorable local condition, and may be exceptional.

FLOWING ARTESIAN WELLS ALONG THE FOX RIVER VALLEY TO GREEN BAY

The Fox river, emptying into Green Bay, has artesian flowing wells from the Upper Cambrian sandstone aquifers developed along its course, from the vicinity of Berlin and Fond du Lac to its mouth at Green Bay, as indicated in the following table:

TABLE 16—*Maximum initial head of wells in the Fox River Valley, south to north.*

City.	Head above sea level.	Head above curb, or the river or lake adjacent.
Fond du Lac	800	About 53 feet above Lake Winnebago.
Berlin	765	About 15 feet above Fox river.
Neenah	760	About 15 feet above Lake Winnebago.
Appleton	730	About 30 feet above foot of locks in Fox river.
Combined Locks	660	About 8 feet above foot of locks in Fox river.
Kaukauna	....	About 35 feet above curb. Badger Paper Co.
DePere	670	About 90 feet above Fox river.
Green Bay	672	About 92 feet above Fox river and Green Bay.

The maximum initial head at Berlin, on the Fox river, was about 15 feet above the level of the river, and at Fond du Lac, at the head of Lake Winnebago, the maximum head recorded was 53 feet above the lake level which is about 35 feet higher than the head at Berlin. The artesian gradient along Lake Winnebago is relatively steep up to the divide between the head of the lake and the head of the Rock river drainage, this section of the valley having the usual characteristic steep artesian gradient at the head of a valley.

The artesian gradient from Berlin to Appleton has a gentle slope showing a decline of about one foot per mile for a distance of 30 miles. From the rapids at Appleton to the foot of the rapids at Kaukauna there is a sharp decline in the artesian slope of 80 or 90 feet in about 10 miles, in conformity with the steep valley slope, the section between Appleton and Kaukauna being characterized by a series of falls and rapids.

From Kaukauna to Green Bay there is only a slight decline in the artesian slope in conformity with the slight fall in the valley floor between these points.

The relatively slight decline in the artesian slope down the Fox river valley between Berlin and Appleton, and between Kaukauna and Green Bay, is probably due, in part at least, to the fact that the valley follows a direction nearly normal to the inclination of the water-bearing strata rather than in the direction parallel to the greatest inclination of the water-bearing strata. The sharp decline in the artesian slope in the vicinity of the rapids, between Appleton and Kaukauna, is probably due, mainly, to the occurrence of a monoclinal fold of the strata in this locality, with the usually accompanying jointing and fissuring of the strata, allowing excessive leakage of the artesian supply.

Flowing Artesian Wells Along the West Shore of Green Bay.

Flowing wells, with source of flow in the sandstone and also in the immediately overlying Galena-Platteville (Trenton) limestone, occur along the west shore of Green Bay with approximate initial heads as indicated in the following table:

Table 17. *Maximum initial head of artesian wells along the west shore of Green Bay.*

City.	Head above sea level.	Head above curb.	Head above Green Bay.
Marinette	613	21	33
Marinette	614	23	34
County Line	624	14	44
Oconto	648	15	68
Oconto	630	11	50
Little Suamico	629	40	49
Little Suamico	671	90	91
Green Bay	672	90	92

At Marinette, the artesian head when the wells were first drilled, reached 30 to 35 feet above the level of the bay; at Oconto the maximum heads reached 50 to 68 feet above the level of the bay; and at Green Bay, the head was orginally 92 feet above the bay. There is very clearly a decline in the artesian heads in going north from Green Bay to Marinette, and this decline may continue for some distance farther north into Michigan, though the heads of the artesian wells in Escanaba, Gladstone, and Rapid River appear to rise again, and closely approximate or slightly exceed those at Marinette and Menominee.

The decline in the artesian head in going north of Green Bay to Marinette, is probably due to the decrease in the thickness combined with the relatively low altitudes of the sandstone in going northeast, as well as the lower altitude of the land and consequently lower water table, in the district west of Oconto and Marinette as compared with the higher land and the higher water table in the vicinity both west and east of Green Bay.

Flowing Artesian Wells Along the Shore of Lake Michigan

The maximum initial head of artesian flowing wells along Lake Michigan, with source of flow in the Upper Cambrian (Potsdam) or St. Peter sandstone, is shown in the following table:

TABLE 18.—*Maximum initial head of flowing artesian wells from the St. Peter or the Upper Cambrian sandstone along Lake Michigan.*

City.	Owner.	Depth of Well.	Head above sea level.	Head above curb.	Head above Lake Michigan.
Algoma	City Well	1,336	Flows from	No pressure from	0
Two Rivers	City Well	1,860	the Niagara.	the sandstone.	0
Sheboygan	City Well	1,476	727	104	146
Sheboyg'n Falls	H. Giddings	1,200	773	55	192
Milwaukee	Story Bros., Highbury Pl.	1,550	738	55	158
Milwaukee	National Soldiers Home.	1,507	766	106	186
Milwaukee	Elm Grove Convent	1,507	790	20	210
Racine	J. J. Fox	1,500	710	80	130
Corliss	C. M. & St. P. Ry. Co.	·1,263	765	60	185
Kenosha	Pennoyer Sanitarium	1,280	720	107	140
Zion City	Zion Ass'n	1,569	665	20	85
Waukegan	Old Waterworks	2,005	675	75	95
Lake Forest	C. B. Farwell	960	700	50	120
Evanston	City Well.	1,602	612	5	37
Chicago	Union Stock Yards	1,200	590	Non-flowing.	10
Harvey	Waterworks	2,075	603	Non-flowing.	13

The productive area of flowing artesian wells with source of flow in the sandstone along Lake Michigan appears to extend from Sheboygan, or a short distance farther north, to Evanston, Ill. (See fig. 13). Many of the earlier flowing wells with strong pressure have ceased to flow, on account of leakage through the well casings and the interference of other wells. The maximum initial head in the various cities from Sheboygan to Kenosha, appears to have usually ranged between 150 feet above the lake level near the shore, up to about 200 feet above the lake 5 or 6 miles west of the shore. The decline in the artesian gradient from west to east, towards the lake, is relatively steep, from 8 to 10 feet per mile, as indicated by the head of 773 feet at Sheboygan Falls, 6 miles from the lake, as compared with the head of 727 feet at Sheboygan, and also by the head of 765 at Corliss, about 6 miles from the lake, as compared with the head of 710 feet at Racine.

South of Kenosha there is a rapid decline in the head, as available records appear to indicate that the strongest flows obtainable from the sandstone at Evanston is only 37 feet above the lake, while in Chicago no flowing wells are obtained from the Potsdam, although flows have been obtained from the Trenton with head as high as 110 feet above the lake. While the artesian head at the Union Stock Yards and at Harvey are a few feet above lake level, the pressure is too low to develop flows. At Lemont,[1] 25 miles west of Chicago, the artesian head of the Potsdam has an altitude of 656 feet, developing a flow 60 feet

[1] W. C. Alden. Chicago Folio No. 81, U. S. Geol. Survey, p. 13.

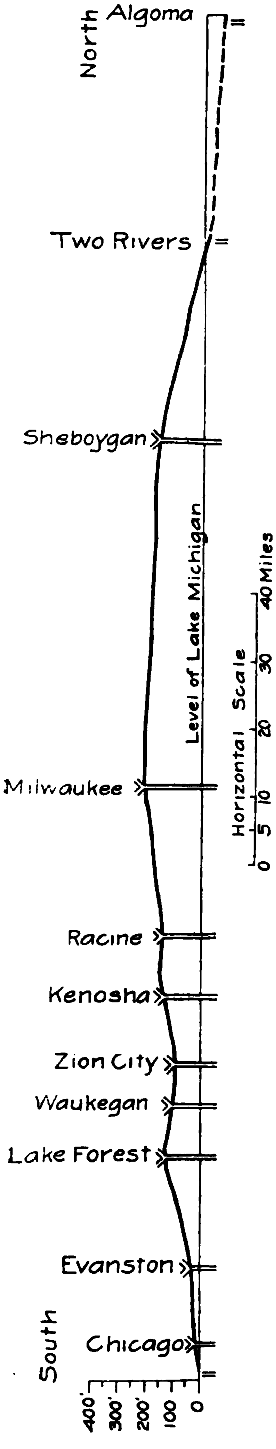


Fig. 13.—Section showing relation of the artesian profiles to the lake level along the west shore of Lake Michigan.

above the curb, and at Aurora, 40 miles west of Chicago, the artesian head is at an altitude of 710 feet, approximately the same as at Kenosha.

The gradual decline in the artesian head in going south of Kenosha along the lake shore to the vicinity of Chicago is probably due, in part to the greater distance of the Chicago district from the outcrop area of the Upper Cambrian (Potsdam) sandstone, as compared with the distance from those cities farther north along the lake, and in part to the lower land, and in consequence a lower groundwater table, about Chicago, as compared with the higher land and the higher water table, in the district farther north.

North of Sheboygan, there appear to be no flowing wells with source of supply in the St. Peter and Upper Cambrian sandstone, although flows from that region are often obtained from the overlying Niagara limestone. The lack of favorable artesian conditions in the Potsdam sandstone in this region is illustrated at Two Rivers and Algoma. Only a small flow was obtained in the Niagara limestone and no flow from the underlying St. Peter and Upper Cambrian (Potsdam) sandstone in the Two Rivers city well drilled 1800 feet to the granite. At Algoma, the new city well drilled 1336 feet deep, 11 feet into the St. Peter sandstone, apparently obtains its entire flow with a head of 22 feet at a depth of 465 feet in the Niagara limestone.

While only these two deep wells to the sandstone group have been drilled along the lake shore north of Sheboygan, both of these failed to obtain flows from the St. Peter or the Upper Cambrian sandstone. The unfavorable geological conditions for developing an effective ar-

tesian area in the Upper Cambrian sandstone north of Sheboygan county are as follows: (1) The gradual decrease in thickness of the sandstone (from 800 down to 400 feet) north of Fond du Lac and Sheboygan counties, and the consequent decrease in the extent of the outcrop area in north-eastern Wisconsin; (2) the relatively low altitude of the sandstone outcrop in north-eastern Wisconsin; and (3) The great increase in thickness (from 300 to over 500 feet) of the Cincinnati shale group in the Green Bay district. The three conditions are all probably influential factors in developing unfavorable artesian conditions in the sandstone group in Manitowoc, Kewaunee, and Door counties. The third factor mentioned, however, the great thickness of the impervious shale, may have the most important effect in developing unfavorable artesian conditions within the sandstone, by preventing the transmission of pressure from the local groundwater table upon the water confined in the sandstone group.

The profile of the artesian head along the shore of Lake Michigan is shown in the section, figure 13.

Flowing Artesian Wells from the Galena-Platteville Limestone

The Galena-Platteville limestone is mainly important in the Wisconsin artesian system as a confining stratum of relatively impervious rock overlying the water-bearing sandstones. While a few flowing wells are obtained from the Trenton limestone, as at Oconto and Fond du Lac, the source of the flows are usually, if not always, from the joints and other openings leading up from the underlying sandstone group within which the artesian water is confined. While artesian wells have penetrated the Galena-Platteville (Trenton) to the underlying sandstone artesian waters in many localities, imperfect casing through the limestone formation has often allowed sufficient leakage from below to develop flows, when wells are later drilled into the limestone. In most cases, however, the artesian pressure is greatly increased by drilling through the Galena-Platteville limestone into the sandstone, thus indicating that the artesian supply in the limestone in eastern Wisconsin has its principal source in the artesian reservoir in the underlying Upper Cambrian and St. Peter sandstone formations.

Flowing Artesian Wells from the Niagara Limestone.

Water confined under hydrostatic pressure within the joints and other openings in the Niagara limestone is much more common than within the Galena-Platteville limestone. The thickly bedded imper-

vious shales of the Cincinnati group, underlying the Niagara, offer an excellent lower confining stratum for the Niagara. It is not uncommon, therefore, to find strong flows from joints in the Niagara at or near the contact with the underlying shale formations.

The red clays of eastern Wisconsin which overlie the Niagara, serves as an upper confining stratum and flows are often obtained in the openings in the jointed and fractured limestone immediately underneath the surface clays on the lower slopes of many of the Niagara uplands. The presence of the overlying confining stratum of clay is not always essential, however, for the underground water in the Niagara ridges and uplands is also, undoubtedly, an important factor in developing artesian pressure on the water confined in the joints and fissures of the limestone.

The flowing wells in the Niagara and those in the overlying surface formations in eastern Wisconsin appear to be so closely related, that it does not appear practicable to separate them on the map (Plate I).

The Niagara formation of jointed rock confined by relatively impervious strata above and below, while furnishing adequate conditions within itself for the development of an artesian system, may also receive important reinforcement in some localities by means of circulation from the underlying artesian reservoir in the Potsdam sandstone group. The reinforcement of artesian pressure in the Niagara through upward circulation from the Potsdam may, in only a few places, be sufficient to be an important factor in developing flows in the Niagara, but the fact that actual circulation of water or at least diffusion of mineral solutions through osmotic pressure operates throughout the deep artesian reservoir in the Potsdam and the shallow reservoir in the Niagara seems to be clearly indicated by the relatively uniform degree of mineralization of the deep and shallow waters in the regions of the Niagara outcrop, as well as in all other parts of the state.

The fact, however, that there is very generally much irregularity in the head of the Niagara artesian supply seems to indicate that the artesian conditions in this formation are largely dependent upon favorable local conditions with reference to joints, topography, elevation and character of the surface deposits. In some places the artesian head of the Niagara is higher than the artesian head of the Potsdam, and in other places it is lower. Near the shore of Lake Michigan south of Manitowoc, the head of the Potsdam artesian supply is higher than that of the Niagara, but as the higher land is reached back from the shore on the divide, flows from the Niagara may be obtained at higher altitudes than from the Potsdam. However, near the shore north of

Manitowoc at Two Rivers and Algoma, flows of 10 to 20 feet above the lake are obtained from the Niagara and no flows obtained from the St. Peter or Potsdam. A similar condition exists in the vicinity of Chicago, where much stronger flows have been obtained from the Niagara than from the deeper water horizons of the St. Peter and Potsdam.

The numerous flowing wells in the vicinity of Rockfield and South Germantown, in southeastern Washington County, are about 160 to 250 feet deep and get their water from the fissures in the Niagara limestone. There are also some springs in the Niagara in section 4 and 5 (see map Plate III). Eight of the springs out of a cluster of 10 on the farm of H. Kramer dried up two days after J. Buescher finished drilling his flowing well in section 16. The same well also dried up the spring on J. Klumb's farm in Sec. 9.

List of flowing wells in the Niagara limestone shown on map of Germantown, T. 9 N. R. 20 E.

Owner.	Location in section.	Depth.		Artesian head, feet.
		Drift, feet.	Limestone, feet.	
Louis Muehle	Cen. 4	30	207	18
L. Berg	Cen. 5	60	156	5
Geo. Muehl	SE. ¼ 5	....	200	....
Philip Kraetsch	SW. ¼ 5	....	256	....
Fred Klumb	NW. ¼ 9	....	....	....
Wm Klumb	SW. ¼ 9	....	....	....
C. & N. W. Ry	NE. ¼ 9	....	200	....
Mr. Mass	NE. ¼ 9	....	220	30
F. Kaul	SE. ¼ 9	....	....	....
F. Kaul	SE. ¼ 9	....	....	....
Mr. Klumb	NW. ¼ 10	3	100	....
Wm. Caspar	SW. ¼ 10	....	....	....
Gus. Haefemeister	NW. ¼ 11	60	166	12
H. Haefemeister	SE. ¼ 14	20	280	40
H. Hinrich	SW. ¼ 14	7	231	....
L. Slater	SE. ¼ 15	....	265	....
Jacob Buesher	SE. ¼ 16	20	172	30
Albert Braun	NE. ¼ 20	....	196	....
Geo. Betzhold	SE. ¼ 20	....	....	....
Ulrich Huber	NW. ¼ 21	....	....	....
Ulrich Huber	NW. ¼ 21	....	....	....
Wm. Hayes	SW. ¼ 21	....	....	....
Thos. Trinwith	SW. ¼ 21	13	118	40
P. Schneider	NW. ¼ 22	....	....	....
Jno. Kissinger	SW. ¼ 22	....	....	....
Reingruber	NW. ¼ 22	....	....	....
D. Strock	NE. ¼ 22	8	25	....
Mr. Braun	NW. ¼ 23	....	196	....
Mr. Schaiefer	NW. ¼ 23	....	....	....
Louis Goettelmann	NE. ¼ 27	....	193	....
Jacob Straub	NW. ¼ 27	5	197	30
San Trinwith	NE. ¼ 28	....	170	....
And. Merkle	NW. ¼ 28	65	191	....
And. Kohl	NE. ¼ 29	....	180	....
And. Merkle	NE. ¼ 29	2	160	4-5
David Klumb	NW. ¼ 29	7	173	....
John Bernard	NW. ¼ 29	....	184	....

Most of the flowing wells about Rockfield and South Germantown, shown on the map, were put down between 1898 and 1902.

The first well striking a flow was drilled by the Chicago and Northwestern Railway Company at Rockfield, in 1898.

Section of C. & N. W. Railway well, Rockfield.

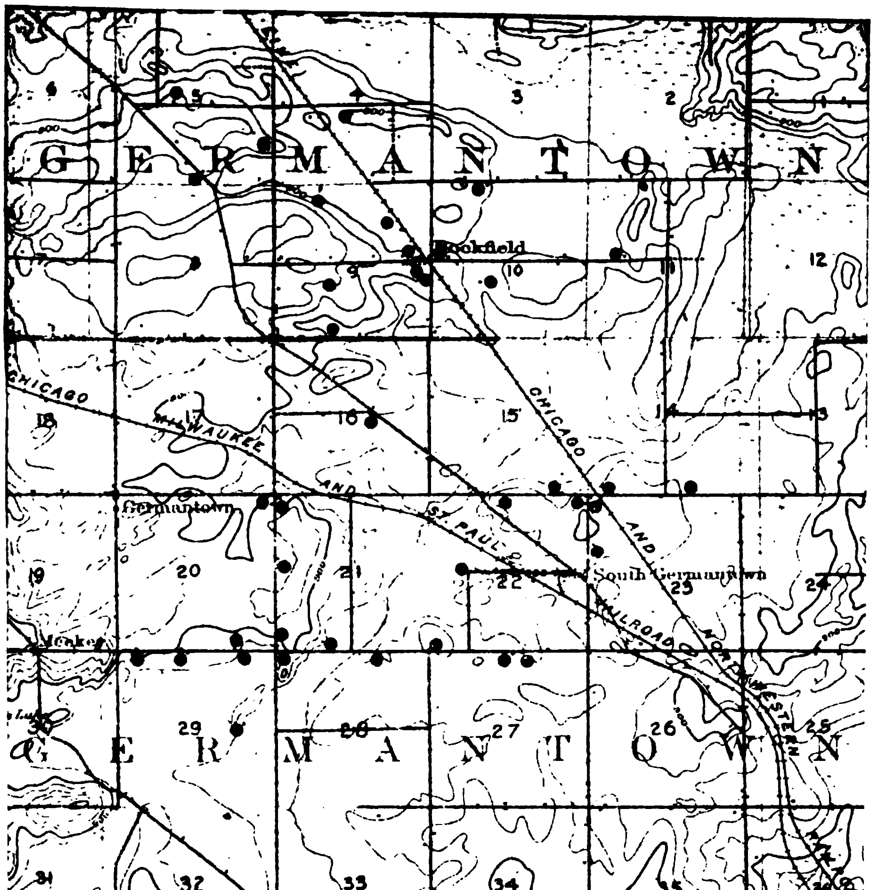
Formation.	Thickness, feet.
Drift	
Soil	2
Niagara	
Soft rotten limestone	78
Hard blue limestone	30
Very hard blue limestone	30
Softer limestone	40
Harder limestone	20
Total depth	200

The altitude of the curb is 891 feet and the original head was 59 feet above the curb or 370 feet above the level of Lake Michigan, and flowed 1,300 gallons per minute. After other wells were drilled, the head decreased and at present the well flows only part of the year and the water must be pumped to the tank.

The other wells of the locality resemble this one very closely. Wells on lower ground take the flow from the higher ones and in some cases have dried them up entirely. At some places, as in Sec. 9, on F. Kaul's farm, the wells flow only occasionally. Most of the owners maintain the pressure of the well by reducing the cap and allowing only enough water to flow for their use.

The character of the Niagara limestone is such as to indicate that the movement of the underground water within it, is almost entirely through fractures, joints and fissures, hence the movement of the water is very likely largely local in extent. The head attained by the artesian wells, also is far above that at all likely to be developed directly or indirectly from the sandstone aquifers. The ready interference in the flow of the wells is also evidence of the essentially local origin of the artesian pressure. The artesian flows in the Niagara, about Rockfield and South Germantown, appear to illustrate very clearly the potent influence of the local groundwater table as the controlling factor in the development of artesian flows.

Litigation relating to Flowing Wells.—In 1900 Andrew Merkel drilled his second well in the N. W. ¼ of Sec. 28 near the Menomonee river, (see map, Pl. III) at the lowest point at which a well had been



TOPOGRAPHIC MAP OF GERMANTOWN, WASHINGTON COUNTY.

The map shows the location of flowing wells in the Niagara limestone represented by the round heavy dots. Besides the lines representing the railroads, wagon roads, streams and marshes there are the contour lines of equal elevation indicating the topography. It will be observed that most of the flowing wells are located mainly along the lower slopes of the uplands, near the marshy tracts. See the list of wells, p. 83.

sunk. Water was struck in a bed of soft rock, but in other places it seems to come partly from fissures in the limestone. This well was allowed free flow into the Menomonee river. This free flow, however, soon made itself felt throughout the district. In three weeks it had stopped the flow of U. Huber's well, about a mile farther north, in the N. W. 1/4 of Sec. 21, which is located on land 20 feet higher, and had also affected most of the other wells of the surrounding area to a greater or less degree. About this time, an injunction was served upon Mr. Merkel by Mr. Huber, for the purpose of compelling him to check the flow of his well, and reduce it to a flow that would approximate that used by his neighbors, and also furnish a sufficient supply for his domestic use. The injunction case was tried in the Circuit court, and the decision was in favor of Huber, and Merkel was ordered to check the flow. The case, however, was carried to the Supreme Court[1] where the law under which it was tried was declared unconstitutional, and the decision was reversed, granting Merkel the right to do with his well as he wished. Since this time very few flowing wells have been drilled in this locality, unless the curb was as low or lower than at the Merkel well. It is unfortunate, that local parties will not agree to maintain so fruitful a source of water supply, by keeping the head throughout the district as high as possible.

Flowing Artesian Wells from Crystalline Rocks

The principles controlling the rare occurrence of artesian flows in the crystalline rocks are the same as those applying to artesian wells in the stratified rocks, but some of the conditions are quite different, as most crystalline rocks have a much closer texture than stratified rocks, and therefore they do not absorb as much water. As a result underground waters are very much less uniformly distributed in the crystalline rocks than in stratified rocks and the chances for obtaining artesian water, or in fact any large quantity of underground water, is relatively very slight.

In view of the fact that large areas of crystalline rocks are either at the surface or immediately underlie the drift and other surface formations in Wisconsin, a somewhat extended discussion of this phase of our water resources appears to be warranted.

Surface Conditions.—Since the crystalline rocks do not so readily absorb and transmit water it is necessary that they should possess some means for allowing the surface waters to sink into them. These condi-

[1] Northwestern Report, Vol. 94, p. 354, and Wis. Reports, Vol. 117, p. 355.

tions are nearly always present in the form of more or less nearly vertical joint fissures, crevices, planes of schistosity, and the like. The amount of water absorbed depends upon the number of such openings.

These fissures, which are often not as broad as a knife's edge, carry off only a small portion of the water offered to them, but the amount of absorbed water may be increased if the crystalline rocks are covered by a more absorbent layer. In many places in Wisconsin the crystalline rocks are more or less deeply buried under the mantle of drift. The drift varies in composition from place to place, but where no layer of clay intervenes between the crystalline rock and the looser-textured drift the water absorbed by the drift will tend to seep into the fissures of the crystalline rock and even be forced into it under pressure. The pressure would originate from the column of underground water maintained above the crystalline surface in the drift. It would vary directly with the degree of saturation of the drift, with the porosity of the drift materials, and with the height of the column of water in the drift; that is, it would depend upon the thickness of the drift and the amount of rainfall.

Underground conditions.—The surface waters, conducted underground by the means above indicated, may move laterally, from place to place, along horizontal joints, fractures, or schistosity planes. Perhaps the most favorable channel for the lateral movement of these waters is along the line of intersection of one or more steeply inclined joint planes with a more nearly horizontal plane. Here water may penetrate downward along two paths and be concentrated at their intersection where it may be led along horizontally for some distance.

Since the crystalline rocks are generally very dense, the waters caught in their joints and fractures, and led or forced down deep enough to penetrate some of the horizontal fractures, will be confined to these latter channels in part on that account alone. A second important factor, however, is the friction encountered by the waters in moving through such fine fissures. This friction, added to the downward pull of gravity, prevents the waters from rising to the surface again by means of the fine cracks. If one may assume here that laws[1] analogous to those holding for pipes express the friction met with by water flowing in cracks of definite width, then it is easy to understand how these waters once slowly forced down by gravity against such friction can not easily rise again, except along unusually large fissures or channels.

Besides these conditions, which may be designated internal, there

[1] Slichter, C. S., Water Supply and Irrigation Paper, U. S. Geol. Surv. No. 67, 1902, pp. 84 and following.

may occur external conditions tending to confine the ground waters in the fissures. Such favorable external conditions are well represented by beds of clay overlying much fissured crystalline rock. It is evident that if the pressure upon the buried waters was insufficient to overcome the friction within the layer of impervious clays which covers the crystalline rocks their escape would be prevented. If an artesian well be driven from the surface of the overlying clays down into the fissured granites it is evident that the many small fissures opening into freer passage through the rock afforded by the well-bores must give up their contained waters, which will rise to a height in the well corresponding to the hydrostatic pressure under which they were confined below the clays. Even if the clay covering were absent, such a well by reason of its larger opening and consequently greatly decreased friction would afford relatively free passage for the waters of the granite.

It is clear that the amount of water supplied to a well under these conditions, depends chiefly upon the number of water-bearing fissures opening into it. This number may be increased by any means calculated to fissure the granite. The most common means is that of exploding a dynamite or other explosive cartridge at the bottom of the well. Even wells which originally yielded no water may be made productive in this way, because the artificial fissures connect the shaft of the well with important water-carrying seams in the rock.

It is evident from the above description of conditions in the crystalline rocks, that the water in these rocks must be irregularly distributed, depending entirely upon the courses followed by the water-bearing fissures. The water is concentrated into channels of greater or less importance, and the chances for striking such channels in crystalline rock is, of course, very small, as compared with the chances of finding a good supply of water in a widely distributed and fully saturated stratum of porous sedimentary rock, like the Upper Cambrian sandstone.

Flowing wells in the crystalline rocks are known to occur only at Wittenberg, Shawano county, in fissured granite overlain by water-bearing drift, and at Penokee, Ashland county, in fissile slate standing at a very steep dip.

Flowing Artesian Wells from the Surface Formations

The artesian wells from surface formations occur wherever the conditions are favorable, but are most regularly and abundantly found in the region of the alluvial and lacustrine deposits near Lake Michigan and Lake Superior. They also extend up many of the rivers emptying into these lakes. Notably is this true for the Fox River in the Green Bay

Valley, where hundreds of flowing wells obtain their supply from between and beneath the alternating beds of clay and sandy gravel. The distribution of the surface flowing wells is shown on the map. (Plate I).

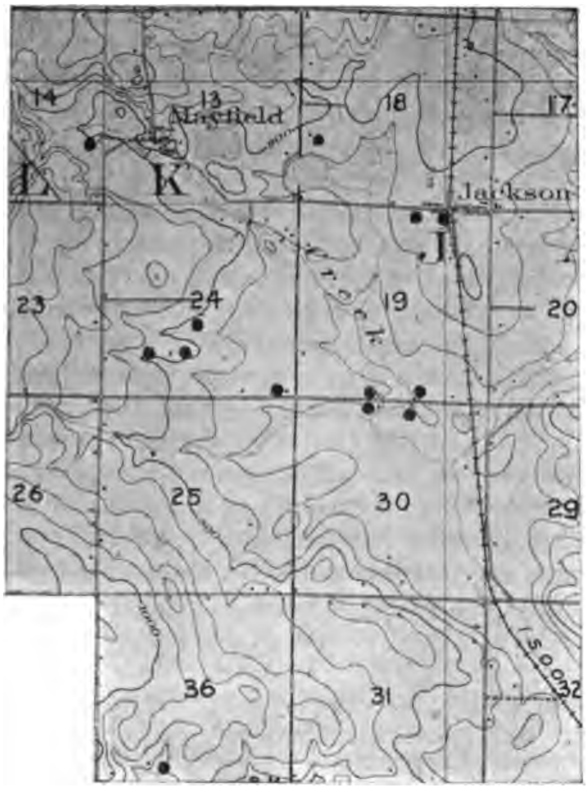
Flowing Wells from the Surface Formations Along Lake Michigan

The surface beds of alternating sands, gravel, and clays which fringe the shore of Lake Michigan, give rise to favorable artesian conditions along the shore and up many of the rivers that drain into the lake. Whether flows can be obtained from these glacio-lacustrine deposits in any particular valley, depends upon the topography and the many other factors that affect artesian flows. In some places along the lake shore the gravel deposits have been completely removed, while at other places they have been so eroded that the waters are no longer confined between the clay beds, but escape by surface streams into the lake.

Lake Michigan and the other Great Lakes formerly covered a much larger area than at present, extending over the more prominent elevations and filling the intervening depressions. Thus the waters in these larger valleys and those of the main lakes were connected and the deposits were probably more or less continuous.

The general distribution, structure, and composition of these glacio-lacustrine and alluvial deposits, and their artesian horizons are discussed in an earlier chapter. The point at which these gravel beds outcrop or where they underlie porous sand and gravel is generally the gathering ground for the water in the artesian slopes. Usually the sand and gravel outcrops occur near the base of the moraines or drift ridges bordering the lake or river basins. Some of the outcrops where the rainfall enters may be several miles from the flowing wells, while others may be within a few hundred feet.

Since the glacial, lacustrine, and alluvial deposits, quite generally fringe the shore of Lake Michigan, it might be inferred that artesian water could everywhere be obtained within the district covered by these deposits. This would likely be true if the deposits were uniform in thickness and were continuous over the entire region, but such is not the case. The gravel beds in many cases are entirely pinched out, in other cases the surface deposits rest upon rock which stand so high as to shut out the lower deposits, thus making it impossible for the development of artesian conditions. In other places, Lake Michigan waters have cut through the gravel beds, and have given the confined waters



TOPOGRAPHIC MAP OF VICINITY OF MAYFIELD AND JACKSON, WASHINGTON COUNTY.

The map shows the locations of flowing wells in the drift represented by the round heavy dots. (See list of wells, p. 89) It will be observed that most of the flowing wells are on low ground along the streams, below the 900-foot contour line.

a chance to escape. For these and other reasons, artesian water, therefore, cannot be obtained everywhere from the surface formations.

Flowing wells, except those derived from the tracts among the moraines of the "Kettle Range" are confined to low-lying lands along the river valleys and the great lakes. While the boundaries of the artesian areas can not be given exactly, wherever the gravel beds are present within the area of the low-lying lacustrine deposits, and erosion has not advanced so far as to furnish a lateral escape, water under hydrostatic pressure, or artesian water, ought to be obtained. In this connection the use of the published topographic maps is of considerable value in determining conditions most favorable for obtaining flows in any given locality.

Since most of the flowing wells in the many small valleys in the eastern part of the state, adjacent to Lake Michigan, are described under the county reports, they will not be referred to here. Relatively important areas of surface flowing wells occur in the valley of the Pigeon river in the town of Meeme, Manitowoc county, and in the town of Herman, Sheboygan county. In these areas is a large number of good flowing wells in the drift which are used extensively for farm purposes. Most of these wells are from 30 to 75 feet deep.

Flowing wells having their source in the drift are very common on low ground along tributaries of the Milwaukee and Menomonie rivers in Milwaukee and Washington counties. The following wells in the drift about Mayfield and Jackson, Washington county, are shown on the map, Pl. IV, and the location and depth of the various wells is shown in the following list:

List of flowing wells in the drift shown on map of area near Mayfield and Jackson, T. 10 N., R. 19 and R. 20 E.

Owner.	Location in section.	Depth feet	Artesian head feet.
Thos. Jehner	SE.¼ 14	70	....
Phillip Straus	Cen. 24	26	....
?	SW.¼ 24	90	Flowed 4 or 5 years.
Wm. Schmidt	SW.¼ 24	54	....
Mr. Kany	SE.¼ 24	....	....
Mr. Hoefor	SW.¼ 36	137	....
Mr. Rosendale	SW.¼ 18	87	22
Mr. Gear	NE.¼ 19	135	5
	NE.¼ 19	90	....
	SE.¼ 19	40–50	....
	SW.¼ 19	40–50	....
	NE.¼ 30	40–50	....
	NW.¼ 30	40–50	....
	SW.¼ 36	....	....

Shallow Flowing Wells Along Fox River and Tributaries.

In the drainage basin of the Fox river is the largest shallow artesian area in Wisconsin. It has an extent of several hundred square miles, mostly in the vicinity of Lake Winnebago and Lake Poygan.

The formations in this valley are similar to those along the small rivers emptying into Lake Michigan. The wells derive their flow from the drift or from alluvial deposits between the impervious clays, and from the junction of the drift with the underlying indurated rock, the rock crevices in places being filled with the water from the gravel seams above, and from the rock below.

Green Bay, De Pere and Kaukauna.—On lower Fox River and its tributaries flows from glacial drift are obtained at various places at Green Bay and De Pere. At Kaukauna, both wells and springs supply water from this horizon along the river banks. The water is often highly impregnated with hydrogen sulphide. In one of the small valleys south of the Paper mill at Kaukauna several flows have been obtained. Some of these wells are as much as 50 feet above the lowest flows along the Fox River bottoms.

Flows have also been obtained from the same horizon east and south of Kaukauna, in the vicinity of St. John, Forest Junction, Chilton, and various other places on the divide in Calumet county. The lacustrine deposits on the divide lie relatively high and the flows are very irregular. For the most part the alternating beach and lacustrine deposits do not occur, but the clay rests directly upon the rock, or upon a thin bed of sand or gravel over the rock, from which the water is obtained.

Appleton.—At Appleton and vicinity flows similar to those at Kaukauna have been obtained from the gravel seams. The well at Mr. Heid's farm may serve as a typical example. It is 55 feet deep and gets its supply from gravel below red clay. The clay is from 40 to 80 feet deep, beneath which leaves, twigs, and logs are often encountered. The water rises several feet above the surface and flows a strong stream. At Menasha and Neenah similar surface flows have been obtained.

Lakes Buttes des Morts.—On both sides of the Upper Fox River, above Oshkosh, flows are obtained from the gravel seams and from the junction of the gravel with the underlying rock. About Big Butte des Morts lake, the area for artesian flows becomes very wide where the lowlands of the former lake basin extended back some distance from the present shore. The same is true for the vicinity of Little Butte des Morts lake. The artesian basin about these lakes extends under the lakes, as was demonstrated near Boone a few years ago, when during

the winter months a camp was established on the lake and in order to get good water a well was sunk through the ice into the gravels below the lake bottom.. The water here rose twelve feet above the surface of the water in the lake and furnished an abundant supply for camp purposes. During the summer months the water continued to rise in the pipe and flowed into the lake.

Omro.—At Omro, flowing wells have been obtained along the river banks and the low marshes bordering the river. In places these lowlands extend back several miles from the river, and flows are very generally obtained around their margins. Within the city of Omro, flowing wells from drift are scattered along the Fox River and within the distance of a mile between the two creameries seven flowing wells have been drilled. These wells get their supply from gravel after passing through 20 to 40 feet of clay, and those on the lowest ground interfere and check the flow of the wells on the higher ground.

South of Omro about the large marsh, flowing wells are obtained at depths of from 40 to 60 feet. The water has a temperature of 48° to 50° F. and is said to be soft, while the water from wells in the rock is hard.

Omro to Berlin.—From Omro to Berlin, numerous flows have been struck on the flats along the river, the gathering ground lying near the margin of the valleys. At Eureka, the wells are very shallow on the east side of the river, some being only 19 feet deep, while west of the river, they are from 32 to 50 feet deep before striking the gravel seam. Six or eight wells have been drilled within the village of Eureka.

South of the village, between Eureka and Berlin, strong flows are obtained all around the south and east side of a large marsh. Near the margin of the marsh, in the vicinity of the large ridges, the water rises 2 to 4 feet above the surface, while on lower ground, it often rises 8 to 18 feet above the surface in 3 or 4-inch pipes. The wells from Eureka to Berlin are from 20 to 60 feet deep. The ridges bounding this marsh are composed of either limestone or gravel and sand. On some of these ridges the sand and gravel is 97 feet thick and affords an admirable catchment ground.

Berlin and Vicinity.—In the vicinity of Berlin flowing wells have been obtained from the gravel and sand horizon at depths of 40 to 60 feet. but at present these flows are largely stopped by the city waterworks plant near the river which draws out one-fourth of its supply from this gravel seam, and the remainder from the underlying Potsdam sandstone; there is a very slight difference between the heads of the two horizons at this place the water being used from both horizons.

South of Berlin along the Fox River much the same conditions exist

as between Berlin and Oshkosh. Flows from drift have been obtained near Princeton, and as far south as Puckaway lake, and are also obtained on the low lands still farther south, about Buffalo lake at Montello, Packwaukee and Endeavor.

Lake Poygan and Vicinity.—Where Wolf river, from the north, empties into Fox river, occurs the most extensive area of artesian water from the drift found within the Fox river and Lake Winnebago basin. This area occupies large tracts of lowlands about Lake Poygan, extending far back to the ridges and hills surrounding the lake. Artesian areas also extend several miles up the stream that empty into the lake, thereby greatly extending the productive region, and increasing the irregularity of its boundaries.

Three miles north of Berlin on the Aurorahville road is a broad low marsh. Along the lowlands surrounding this marsh and up a number of the valleys flows have been obtained. Some of the farms have three and four wells, but fail to get flows at the house or barn-yard because the elevation about the buildings is too high. Most of the wells are 2 inches in diameter either driven or bored, passing through 40 to 60 feet of clay, then into a gravel bed that supplies the water.

From the vicinity of Berlin to Aurorahville, flows have been obtained everywhere along the road on low ground, while on the higher elevations the water rises nearly to the surface. Flows have also been obtained 2 miles west of Aurorahville, at Packerville, at Fargoville, and at Terrill.

Aurorahville and vicinity.—The oldest well in Aurorahville was drilled about 1868 and is still one of the strongest flowing wells of the locality. It is located near the mill pond, opposite Well's store. The well is cased with 4-inch pipe for 10 feet and the remainder is 3 inch casing. The depth of the well is 95 feet, and the temperature of the water is 50 F. which is also the temperature of the other well waters.

There are many flowing wells in the vicinity of Aurorahville. The water is struck at three or four distinct horizons separated from each other by beds of clay 20 to 60 feet thick. The wells usually range in depth from 25 to 350 feet without entering rock, but at some few wells the Potsdam sandstone is entered at 100 or 120 feet. No doubt this underlying sandstone helps to supply the gravel seams in certain localities where the artesian head of the water in the gravel seams is lower than that in the Potsdam.

Along the road from Aurorahville to Poysippi, the same type of surface flowing wells are seen on the lower elevations. As Poysippi is approached, the ridge swings toward the east and confines the productive

area nearer to Lake Poygan. Numerous flows have been obtained in the village of Poysippi, near the banks of the little creek flowing through the town. Artesian flows have been obtained for some distance up this little valley to the vicinity of Pine River and Saxeville.

The productive area of flowing wells about Poysippi swings eastward from Poysippi along the base of the ridge around the eastern projection, and extends westward on the north side of the hill to a point within a few miles west of Brushville. Flows may be obtained anywhere along the small creek between Brushville and Tustin.

In the latter village it is claimed that no pumps have been used, all the water coming from artesian wells whose waters generally flow several feet above the surface of the ground.

North of Brushville, in the vicinity of West Bloomfield, numerous flows are reported. At Fremont many similar flows are obtained. At Dale the wells range in depth from 72 to 300 feet, and obtain flows from the gravel seams.

At Medina a flowing well at the stock yards is 65 feet deep. Other flows have been obtained on favorable ground. Similar wells are struck in the vicinity of Medina Junction, particularly along the small streams.

South of Lake Poygan, flows are obtained all along the lake from the Aurorahville marshes to Winneconne, at Borth, and at Poygan, and between these places. The porus drift ridges surrounding the basin, furnish the gathering ground for the artesian waters. It is to be expected that flows may be obtained wherever the topography is favorable and the land is low.

Within the towns of Warren (T. 18, R. 12) and Aurora (T. 18, R. 13) the flowing wells are numbered by the hundred, and the following records compiled in 1903 by A. R. Heald, driller, show the various kind of wells obtained. Water is struck in sand and gravel after passing through beds of clay of various thickness. For the most part only one of the gravel seams is used at a given well.

TABLE 19—*Logs of flowing wells in Warren, Aurora and vicinity.*
(Authority, A. R. Heald, Driller).

Owner.	Location.			Year drilled.	Size, inches.	Total depth, feet.	Strata passed through		
	T.	R.	Sec:				Clay.	Sand or gravel, feet.	Rock, feet.
A. Moshen	18	12	12	....	3	60	....	....	....
Michael Albright	18	13	1	1888	2	115	115	....	....
O. Schonschek	18	13	1	1894	2	101	100	30	....
S. A. Harrison	19	13	3	1889	2	72	72	....	....
A. Stewart	18	13	3	1895	2	96	96	....	....
P. Morrow	18	13	8	1899	2	98	98	....	....
W. H. Elmer	18	13	4	1899	....	213	213	....	....
E. Smith	18	13	5	1888	2	58	58	....	....
E. Chapin	18	13	6	1888	2	125	120	s. 5	....
Levi Warren	18	13	6	....	....	....	....	....	....
E. E. Wells	18	13	6	1895	2	124	95	s. 29	....
Aurorahville Creamery	18	13	6	1894	2	290	89	s. 170	31
Aurorahville School	18	13	6	....	2	....	....	....	....
J. B. Davenport	18	13	6	1895	2	127	95	s. 22	....
J. W. Hollenbeck	18	13	7	1895	2	110	95	s. 15	....
T. S. Hall	18	13	7	1895	2	120	95	s. 20	....
Aurorahville Fountain	11	13	7	1896	4	95	95	....	....
J. Ostram	18	13	11	1901	2	119	119	....	....
J. Pralish	18	13	11	1899	2	124	122	g. 2	....
J. J. Clark	18	13	13	1897	2	250	135	g. 115	....
Geo. Eldredge	18	13	14	1901	2	150	150	....	....
M. Rivers	18	12	14	1902	2	100	100	....	....
B. T. Davenport	18	13	17	1895	2	60	60	....	....
B. T Davenport	18	13	17	1898	2	68	68	....	....
M. Hoose	18	13	19	1903	2	92	92	....	....
T. Curren	18	13	20	1888	2	160	125	....	35
Elliot Davis	18	13	20	1888	2	145	145	....	....
Dave Evans	18	13	21	1896	2	160	160	....	....
Wm. Owens	18	13	22	1888	2	300	300	....	....
M. Meesick	18	13	26	1902	2	140	140	....	....
Mrs. Crousl	18	13	29	1902	....	25	25	....	....
M. Rivers	18	13	29	1903	2	70	70	....	....
A. Mehl	19	12	34	....	....	200	200	....	....
A. Mehl	19	12	34	....	....	162	162	....	....
S. Ware	19	12	33	....	4	80	....	....	....
E. M. Eoville	19	12	35	1892	2	175	150	s. 25	....
E. M. Mathews	19	12	36	1892	2	107	95	s. 12	....
E. M. Mathews, No. 2	19	12	36	1892	2	185	130	s. 55	....
A. Heald	19	12	36	....	....	250	250	....	....
Mrs. Hearnsberg	19	13	1	....	2	88	60	....	ss. 28
Chas. Benedict	19	18	7	1903	2	60	60	....	....
Chas. Ellet	19	13	15	1902	2	119	119	....	....
C. Ellet	19	13	20	1898	2	100	100	....	....
P. Hanson	19	13	20	....	4	40	....	....	....
T. Schroeaden	19	13	25	1898	2	368	254	g. 70	....
G. Schonscheck	19	13	25	....	2	127	100	g. 27	....
A. Borth	19	13	25	1895	2	168	150	g. 18	....
F. Cassady	19	13	27	1902	2	55	30	g. 25	....
E. Gherkie	19	13	29	....	4	80	80	....	....
Mrs. Cate	19	13	31	1896	2	181	108	s. 93	....
Mrs. Cate	19	13	31	1890	2	190	190	....	....
Mrs. Blase	19	13	31	....	....	100	50	g. 40	10
W. Cahin	19	13	31	....	3	80	....	....	....
N. Pierce	19	13	32	....	3	80	....	....	....
C. Rodencil	19	13	32	1901	2	55	55	....	....
E. Gherkie	19	13	32	1901	2	90	90	....	....
D. Thomas	19	13	32	....	3	80	80	....	....
Mr. Rockitt	19	13	33	1896	2	277	250	g 20	....
Lew Dice	19	13	34	1896	2	311	266	g. 45	....
M. Fralish	19	13	34	....	2	133	133	....	....
Mr. Meshesin	19	13	34	....	2	170	170	....	....
C. Hoeft	19	13	34	....	2	175	175	....	....
Mr. Blam	19	13	34	....	2	170	170	....	....
M. Pralish	19	13	34	1899	2	133	133	....	....
Mr. Buhrow	19	13	35	....	2	224	220	g. 4	....
R. Wilkie	19	13	35	....	2	281	200	g. 31	....
George Dise	19	13	35	....	2	80	77	....	3 ss.

TABLE 19—*Logs of flowing wells in Warren, Aurora and vicinity*—Concluded.
Authority, A. R. Heald, Driller.

Owner.	Location.			Year drilled.	Size inches.	Total depth.	Strata passed through.		
	T.	R.	Sec.				Clay.	Sand or gravel feet.	Rock feet.
Mr. Stermstki	19	13	36	....	2	162	150	g. 12	....
Mr. Belter	19	13	36	1895	....	113	33	g. 40	40 ss.
E. Trehtow	19	13	36	1896	2	270	250	g. 20	....
W. Batkie	19	13	36	1899	2	248	235	g. 13	....
Mr. Laymen	19	13	36	1899	2	96	45	g. 50	....
Berry Creamery	19	14	30	1899	2	182	150	s. 22	....
Chas. Nitzki	19	14	30	....	2	190	100	g. 90	....
Chas. Nitzki	19	14	30	....	2	175	100	g. 75	....
Poyan Creamery	19	14	......	1894	2	120	50	g. 70	....
Mr. Palmeter	Berlin City			1892	4	69	58	g. 10	1
L. Wares	Eureka			1892	2	51	16	....	35
H. Barden	Eureka			1893	2	110	105	....	5
W. W. Noble	Eureka			1893	4	87	63	....	24.ls.
M. J. Rounds	Eureka			1893	2	69	....	g. 69	....
A. M. Goucher	Eureka			....	2	40	9	....	31.ss.
Mr. Craig	Eureka			....	2	37	37	....	....
Koro Creamery	Eureka			....	2	64	....	g. 17	....
Eureka Creamery	....			....	2	85	32	s. 43	10.ss.
R. Oaks	Eureka			....	2	106	100	....	6
A. Oaks	Eureka			....	2	53	53	....	....
Mrs. Lee	Rushford			....	2	94	69	....	25
M. Heisinger	Rushford			....	2	45	45	....	....
Mr. Zink	Rushford			....	2	45	45	....	....

FLOWING WELLS ALONG WOLF RIVER AND ITS TRIBUTARIES

North of Lake Poygan along Wolf river and its tributaries the lacustrine deposits occupy a considerable area extending from Lake Poygan northward to and embracing Lake Shawano. This area has a width of 20 miles at the south, in the vicinity of New London, and about 12 miles at the north, near Shawano. The area extends on each side of the river bank to the sand ridges which form the divides and serve as a catchment ground. Over most of this area water under hydrostatic pressure is obtained, but flowing wells are chiefly obtained only on the lowlands along the Wolf river and its tributaries.

The depth of the wells ranges from 30 to 250 feet and water is drawn from three distinct gravel horizons. Water is obtained at depths of 20 to 30 feet, of 120 to 150 feet and of 202 to 250 feet.

The flows are generally small. They range however, from a stream which breaks into drops in falling, to strong flows filling a 3 inch pipe as in the case of Mr. Ramm's well of New London. The water is clear and wholesome, has a temperature of 48° to 50° F. and in some instances is impregnated with moderate amounts of iron and hydrogen sulphide.

In New London are a number of flowing wells in the surface formations of sand clay and gravel drilled to a depth of 200 to 250 feet, striking either the granite at bottom or a thin bed of sandstone overlying the granite.

The National Condensing Milk Co. has a well 252 feet deep, 8 in casing, with average flow a few feet above the river of about 72,000 gallons per day. At the Chair Factory, water is piped from a flowing well having an estimated capacity of 36,000 gallons per day.

Ramm's Fountain has a depth of 220 feet, 4 in. pipe, and a daily flow of about 30,000 gallons. The curb of this well is 20 or 30 feet above the river level.

Shallow Flowing Wells in Rock River Valley

Flowing wells from the surface deposits are fairly common along the Rock River, and also along the many tributaries of the Rock, the flows coming from the sand and gravel beds lying below impervious beds of clay.

Flows are obtained irregularly along the banks of the Rock River from this horizon all the way from the mouth to the source. Flows of this kind are obtained at Dixon, Illinois, from wells 94 to 120 feet deep; at Oregon, Illinois, where the supply may be in part from the underlying St. Peter sandstone which in this locality helps feed the sand and gravel seam; and at Beloit, Wisconsin where the supply again is partly from the St. Peter horizon. The water at Beloit is struck in a gravel seam below clay at a depth of about 90 feet. More than 36 of these wells have been driven within the city of Beloit. The water rises a few feet above the surface and in some cases as high as 8 feet. Flows are, however, confined to the lowest ground near the bank of the Rock river.

Flowing wells from glacial drift are obtained all around Lake Koshkonong, and up Rock River and many of its tributaries. Flows have been obtained along the banks of the Rock, Koshkonong, Bark, Whitewater, Scupernong, and their important tributaries, covering a large area in Walworth, Rock, Waukesha, and Jefferson counties.

Flowing Wells About Lake Koshkonong

All these are on low ground about the lake or near the river bottoms. In this vicinity is a lake basin covering the area once occupied by the predecessor of the present Lake Koshkonong which extends up the present tributaries of the various streams that flow into the present lake. Flowing wells south, north and east of Whitewater, around Heb-

ron, west of Palmyra, as well as around Lake Koshkonong, do not strike rock. They are confined to the drift and are possible because the bed of lacustrine clay, forming the level plain about the present lake and along the river beds, rests upon the flank of much higher lying drift hills to the southeast with sandy and gravelly prairies behind them. These sandy and gravelly plains are admirably adapted to serve as collecting areas for the shallow artesian area.

These collecting areas surround the entire basin and extend along the sides of the streams and are much higher than the region where flows are obtained.

Strong flows are obtained as soon as the drill or auger passes through the clay bed into the gravel seam. South of Lake Koshkonong flows are struck at several coarse gravel horizons, at 40 feet, at 151 feet, and at 186 feet. At Koshkonong a deep well on the Black Hawk was drilled almost entirely through clay and shows the extreme depth of the clay deposits as well as the pinching out of certain gravel seams.

Flows have been obtained at other points along Rock River, up such tributaries, as the Yahara and Crawfish rivers. At Madison a flow was obtained from the drift near Lake Monona at a depth of 119 feet. This well was drilled by the American Plow works in 1903.

On Crawfish River flowing wells are struck at various places in the drift near the river banks. At Columbus many of the wells are in part, at least, fed by the underlying St. Peter sandstone which also furnishes good flows. Although no exact basin can be outlined for these wells, it seems probable from the data thus far gathered, that flows will be obtained from glacial drift at other favorable points along the Rock river and its tributaries, particularly along the low basins.

Other flows have been obtained farther north on Rock River in the vicinity of Waupun, and on its tributaries as far up as Beaver Dam on Beaver Dam River, but not enough data are at hand to state whether they are all of the same general type. However, since most of them are struck along the river valley, or around lakes, it appears that they receive their flow from the deposits of sand and gravel beds covered with impervious clay that were laid down in these drainage basins.

Flowing Wells Along Lake Superior

Along the south shore of Lake Superior are surface deposits like those that occur along the shore of Lake Michigan and of Green Bay. The general structure and geological relations are the same in the two regions, although the general distribution of the deposits is probably

more irregular along the shore of Lake Superior than along Lake Michigan. The artesian slope along Lake Superior is mainly confined to the immediate vicinity of the lake. The alternating beds of sands, clays, and gravels fringe the shore of Lake Superior and dip toward the lake. The gathering ground for the waters lies between the lake and the prominent trap ridge some 10 to 20 miles south. These clays with interbedded gravels and sands extend from Superior, Douglas County, Wis., eastward to Ontonogan county, Mich., and give rise to flowing wells along the lowlands bordering the shore. Farther back from the shore, where the ground is considerably higher, the water usually fails to reach the surface. At Superior the water rises 22 feet above lake level, while at Ashland it rises 30 to 44 feet above lake level. These, however, are maximum initial heads and in most wells the present head is considerably lower. At other places various heads are maintained depending upon the local conditions. See also the local descriptions of Douglas, Bayfield, Ashland and Iron counties.

Isolated Areas of Surface Flows

While most of the surface flowing wells occur along the shores of Lake Michigan and Lake Superior and along the large river valleys of the eastern part of the state, occasionally favorable conditions in surface deposits are found elsewhere for the development of artesian flows.

At Arkansaw in Pepin county on the banks of the Eau Galle river, a good flow has been obtained at depth of 120 to 140 feet in the alluvial gravel under clay strata. At Hudson in St. Croix county, the trout springs along the Willow river are supplied by numerous shallow flowing wells consisting of pipes driven into the surface gravels and sands. In the vicinity of Osceola, Polk county, are numerous flowing wells along Osceola creek, in the surface formation, at depth of 10 to 20 feet.

CHAPTER IV.

PROSPECTING FOR FLOWING WELLS

The head of any artesian well depends upon a number of factors, and cannot be predicted with any degree of accuracy, unless the local geological and topographic conditions, are fully considered in connection with the general principles controlling or modifying artesian pressure. The influences of certain artesian factors are probably not as fully understood as they should be, and required data concerning the actual underground geological conditions is also not available in certain localities, hence, it is necessary, to exercise considerable caution in making predictions in regard to flows. However, the prospecting for flowing artesian wells, as well as for non-flowing artesian wells, is an important practical problem, and the possibility or probability of obtaining flowing wells has always attracted the attention of well drillers and property owners in search of the best available water supplies in nearly every part of the state.

In Chapter II, the general condition controlling or modifying artesian wells have been briefly referred to, and in Chapter III., the various flowing artesian wells over the entire state have been described. In the present chapter, a repetition of some of the statements already made will be necessary in connection with the discussion of prospecting for flowing wells.

The influence of the local water table on artesian pressure. While Professor Chamberlin was probably the first to call attention to the influence exerted by the local ground-water level on the artesian head, in his geological report[1] of Wisconsin, he apparently, did not, at first, fully appreciate the importance of this factor. In his later work[2] on artesian wells, however, he called attention to the local groundwater table as exerting very favorable conditions for securing flowing wells. He stated:

"I conceive that one of the most favorable conditions for securing a fountain is found when thick semi-porous beds constantly saturated with water

[1] Geol. of Wis., Vol. 1, p. 689–70, 1881.
[2] U. S. Geol. Survey, 5th Ann. Rept. pp. 125–173, 1885.

to a greater height than the fountain head, lie upon the porous stratum and occupy the whole country between the well and its source."

Concerning the height of adjacent water levels M. L. Fuller[1] has recently stated:

"The height of the water table over any point in an artesian system may exert a material influence on the pressure. In fact, this may be a far more important factor than the pressure transmitted from the more remote catchment area."

It is apparent when the distribution of the flowing wells in the water-bearing Paleozoic rocks in Wisconsin is considered, that the occurrence of many of the flowing wells at relatively high elevations can be explained only on the theory that the local groundwater level in the overlying strata is the principal factor in determining the artesian head.

The influence of the pressure of the local groundwater on the artesian head, is called especial attention to, as it undoubtedly, is not only far more important in Wisconsin, than has been generally supposed, but is, very apparently, far more important, in many other localities, than the factor of transmitted pressure from the more remote catchment area of the various artesian systems involved.

In considering the influence of the local groundwater level, the effect does not appear to be conditioned upon, or restricted to, the location of the groundwater table between the proposed well and the catchment or outcrop area of the water-bearing stratum in which the well has its source. The high water table may be located on either side of the proposed well with respect to the catchment area, and exert an equally potent influence on the local artesian head. The essential truth of this inference is based on such facts as the occurrence of the relatively high head attained by the flowing artesian wells in the Upper Cambrian (Potsdam) on the east side of the Fox river valley, at Beaver Dam, Waupun and Horicon, at elevations respectively of 886, 883 and 860 feet, as compared with the much lower artesian head, between the above flowing wells and the sandstone outcrop, of 765 feet at Berlin, and under 800 feet elsewhere farther up the Fox river valley. In a similar way, as high a head is maintained in the artesian wells at Whitewater, on the east side of the Rock river, as at Waterloo and Cambridge, on the west side, though the latter places lie much nearer the sandstone outcrop than does Whitewater. ***Other conditions being equal, the greater the proximity of the local high water table to the well, the greater is the***

[1] U. S. Geol. Survey. Bull. 319, p. 31.

influence exerted by the local water table on the artesian head of the well.

For this reason, therefore, the artesian or hydraulic gradient rises and falls with the height of the local water table, being lower within the valleys than upon the divides, causing the areas of estimated equal artesian pressure, indicated by artesian contours on the general map, to follow the general contours of the land surface, (see also page 55) thereby developing regions of high artesian pressure on the high divides between the principal drainage systems of the state and regions of relatively low artesian pressure within the adjacent low valley plains.

The factor of the increased pressure upon the artesian aquifers in consequence of the height of the local water table, therefore, must always be taken into consideration in predicting favorable areas for artesian flows. Because this factor was largely overlooked former estimations[1] concerning the head of artesian wells obtainable in various parts of the state and especially in the Mississippi river district are far too low. In these earlier estimates, it was predicted, that although flows up to 200 feet, and even higher, might be secured in the Mississippi river district, the probabilities were fair for success, at elevations not more than 100 feet above Lake Michigan.

Artesian flows, however, have been obtained at much higher elevations than were predicted in 1881, the flows along the valleys tributary to the Mississippi being as high as over 400 feet above Lake Michigan, the flow at Wilton in the Kickapoo valley being at an elevation of 991 feet above sea level.

Artesian flows in eastern Wisconsin, along the Rock river valley, and adjacent to Lake Michigan, are obtained at least over 50 feet higher than the usual maximum head formerly predicted, and may reasonably be predicted at still higher elevations.

These former predictions, as already stated, were largely based on the relative elevation of the outcropping edges of the water-bearing strata, as compared with that of the well from which the artesian water was obtained, after giving an allowance of about one foot per mile for the distance between the collecting area and site of the well, for obstruction offered by the transmitting rock, and leakage of the confining strata.

It now appears, from later investigation and the development of many additional data concerning artesian wells, that the height of the water table over any point, very generally, is a far more important factor in Wisconsin in developing pressure in the artesian systems than the pressure transmitted from the more remote catchment area.

[1] Geol. of Wis., Vol. 1, p. 698.

The following predictions, concerning areas in which success is probable, are based on the inference, that the pressure exerted by the local water table, is usually, the most important factor in developing conditions favorable for obtaining artesian flows.

Areas in which Success is Probable

The general geological map Plate I, in pocket, showing the artesian contours of the St. Peter and Upper Cambrian (Potsdam) artesian system, should be studied in any investigation of the artesian conditions of various localities of the state. The contours, as drawn on the map, are necessarily very much generalized, partly because sufficiently exact knowledge of the artesian conditions over considerable areas cannot be secured, and partly because of the small scale of the map. The artesian contour lines refer to the artesian head of the non-flowing as well as the flowing artesian wells, and, therefore, the contours do not themselves indicate the exact height at which flows are obtainable. It is usulaly only on low land, within the valleys, that flows are secured, the flowing wells being located where the bottoms of the valleys fall below the artesian contours, thus bringing the artesian head above the land surface.

Western Wisconsin. In western Wisconsin, in the valleys tributary to the Mississippi river, artesian flows from the Upper Cambrian (Potsdam) sandstone have been obtained with head, in one instance, reaching an elevation of over 400 feet above the level of the Mississippi river. The relatively high heads of the artesian wells are not exceptional nor confined to any particular localized area in western Wisconsin, but are general over the entire territory. However, the artesian conditions of each valley, such as that of the main Mississippi river as well as that of each tributary, must be considered separately in any discussion of locating artesian wells. The description of the artesian wells of the various valleys in which flows have been obtained, has been quite fully stated, and need not be repeated here, except merely to mention that flowing wells are common in the following valleys: The Mississippi valley; the Chippewa valley; the Red Cedar valley; the Beef valley; the Trempealeau valley; the La Crosse valley; the Coon Creek valley; the Kickapoo valley; and the Baraboo valley. (See pages 64 to 74.)

The distribution of the flowing wells within these valleys, and their respective initial maximum heads, are fully described and explanations offered for the non-productive sections of these valleys, and in some cases suggestions are made concerning the probability of success in locating flows in portions of the valleys not already explored.

The available head of flowing wells, within the Mississippi valley is usually from 25 to 100 feet above the river level adjacent, while the available heads in the tributary valleys are usually below 50 feet above the adjacent river level. The general range in artesian head in the small valleys, is usually, from a maximum of 50 feet above river level down to a minimum some distance below river level.

The development of artesian flows along the Mississippi river and within the tributary valleys illustrate clearly the very potent influence of local geological and topographic features, and the consequent development of favorable local groundwater pressures on the artesian reservoir. The artesian gradients, within the valleys, conform closely to the gradients of the valley bottom, and local conditions of valley topography are features of paramount consideration in predicting the location of areas, within valleys, where success in obtaining flows may be attained. While the artesian head is always higher in the uplands than within the valleys, as already stated, it is only on the low ground, within the valleys, that favorable conditions for obtaining flows above the surface are developed.

In connection with the discussion of the subject of flowing wells in western Wisconsin, it may be helpful to point out at least two local conditions that should be taken into consideration in prospecting for artesian flows. These conditions are undoubtedly applicable to all parts of the state, but they appear to be best illustrated along the Mississippi river, where the valleys have not been abruptly modified or blocked by glacial deposits.

Sections of valleys with the average, or higher than the average slope, are more favorable for the development of flows, than sections with little, or less than the average slope.—The distribution of flowing wells in the La Crosse valley and in the Baraboo valley, shows that the flat parts of these valleys are characteristically non-productive of artesian flows. The diagrams, Figs. 10 and 12, illustrate the artesian conditions in these valleys, and indicate how the artesian heads above the surface in the upper parts of the valley, decline at a relatively constant gradient in passing down the valley, and fall below the valley surface, where the latter is nearly flat for a considerable distance. In the La Crosse valley, the nearly flat section of the valley, lies in the lower-middle part of the valley, between Bangor and West Salem, while the nearly flat part of the Baraboo valley, lies at the lower end of the valley, a few miles below Baraboo, near the Wisconsin river.

The head of the flowing wells in passing down the valleys declines at a certain fairly uniform rate, and this decline is generally known as the

hydraulic, or artesian, gradient. The valley bottom in passing down the valley also declines at a more or less uniform rate, and this decline is generally known as the valley gradient, or the stream gradient. There is also a decline in the level of the groundwater, the surface of the groundwater table, conforming closely to, but located some distance below the land surface in passing down the valley, which may be conveniently referred to as the local groundwater gradient.

While the pressure upon the artesian reservoir transmitted from the more remote catchment area, is an important factor, the height of the water table over any point usually exerts a still more powerful influence on the artesian pressure, and, therefore, the resultant artesian head in valleys is largely a function of the local groundwater level within each valley area.

The artesian gradient, illustrated in the diagrams, Figs. 10, 11, and 12, is above the valley bottom in some sections of the valleys and below in others, depending upon the relative position of the artesian gradient to the slope of the valley. The artesian gradient, which is the head, or height the water under pressure will rise in the artesian wells, very obviously, forms a more uniform slope in some valleys than the local valley bottom, and hence, in those sections of such valleys that are nearly flat, or are below the average slope of the rest of the valley for a considerable distance, the more uniform and consistent artesian gradient will usually fall below the valley surface.

It may not be out of place at this point, to refer to the generally erroneous belief, that flat sections of valleys are more favorable for the development of artesian flows than the steeper slopes, whereas experience has shown, that the flat parts of valleys, in most cases, as above indicated, are the least favorable for the development of flows. This erroneous belief is based, in part at least, on the supposition that pressure within the artesian reservoirs was mainly transmitted from the more remote catchment area. While the dip of the water-bearing strata in the artesian system, and the consequent pressure transmitted from the catchment area, is undoubtedly a factor of some importance, it is, apparently, not so important in the semi-porous strata of the Wisconsin systems, as the pressure exerted by the local groundwater table.

Areas near high uplands or at the base of bluffs in the valleys are more favorable for flows than areas more remote.—The location of flowing wells adjacent to high bluffs in valleys appears to be due to the fact that these places are more favorably situated for receiving the pressure transmitted from the local high water table standing in the adjacent bluffs and uplands than locations farther out in the valley that

are more remote from the high water table. The artesian gradient descends down the sides of valleys just as it descends down the middle of the valleys the descent down the sides of the valleys, however, being much more rapid than that down the middle of the valley. The difference in head immediately adjacent to the bluffs and that out in the middle of the valley may not be great, depending much upon the width of the valley, but it may be sufficient to determine whether the well is of the flowing or non-flowing type.

It is also very probable, that conditions for the maintenance of the artesian head, are much more favorable in locations immediately adjacent to a high water table than in locations more remote from such a high water table. Favorable conditions for the maintenance of the artesian head, is undoubtedly, far more important than that of obtaining a high initial head.

The difference in head, obtained by artesian wells along the Mississippi river, is very probably largely due to the relative position of the wells with respect to the adjacent upland, containing relatively high or low groundwater tables. The lowest artesian heads, attained along the Mississippi in Wisconsin, (See table 7 page 64) are those in the vicinity of La Crosse, where, on account of the great width of the valley and lower adjacent uplands, the most unfavorable conditions for reinforcement of the artesian pressure from the more distant and lower groundwater table are developed. Farther north, at Red Wing, which lies at the base of the river bluffs, and also farther south, at McGregor and Dubuque, which also lie close against the high river bluffs, the artesian head is high, because in these locations the conditions are very favorable for the utilization of pressure from the adjacent high groundwater table.

The relatively strong artesian head of the wells developed at Durand on the Chippewa river, is undoubtedly due to the favorable location of the wells along the base of the high bluffs, where reinforcement of artesian pressure from the adjacent high water table is effective.

The above described two sets of conditions are features generally characteristic of all the valleys of the state, and should be considered in prospecting for flowing artesian wells.

There are various valleys in Wisconsin, in which no flowing wells have been located, but which appear from their location and topography to be favorable territory for exploration. The general statement should perhaps be made, that the localities for obtaining flowing artesian wells in Wisconsin are by no means exhausted. The prospect for finding flows in many valleys not yet productive appears to be good. In

the following statement, some of the valleys where success is probable, will be pointed out. In many instances, the valleys or sections of valleys where prospects for obtaining flows are good, are also pointed out under the county descriptions.

Valleys in Western Wisconsin in which Artesian Flows may be Obtained.—Flowing wells with source of flow in the Upper Cambrian (Potsdam) sandstone occur along the Mississippi and tributary valleys from Polk county on the north to Grant county on the south.

Beginning at the north, flows are quite common along the St. Croix river between Osceola and St. Croix Falls. The flowing wells in this district are generally shallow, usually less than 100 or 200 feet deep, and depend upon favorable local geological and topographic conditions. The source of the flows may be developed entirely within the sandstone formation, consisting of alternating shale and sandstone beds, or they may be developed at the contact of the sandstone formation with the underlying Keweenawan trap, the latter type of artesian well being illustrated by the flowing salt well, about 3 miles north of Osceola.

While flows have not been developed along the St. Croix river at Hudson, the conditions being unfavorable, as described on page 548, it seems quite likely that flows with low head may be developed in portions of the Apple River valley, at favorable locations below rapids in the section of the river lying between the St. Croix river and the village of Star Prairie. Several flows have been obtained in the Kinnickinick valley at River Falls, and conditions appear to be favorable for obtaining additional flows on low ground, along the very narrow river valley below River Falls. Conditions should also be favorable for strong artesian flows near the mouth of St. Croix river, below the Ilwaco springs.

Some of the valleys tributary to the Red Cedar, Chippewa and Mississippi rivers in southern Pierce, western Dunn and western Pepin counties appear to furnish conditions favorable for the development of flows. Most of these valleys head in St. Croix county, but the valley bottoms in St. Croix county are probably too high in elevation for developing flows. Although no flows have been developed in these valleys, in sections of such valleys as the Trimbelle river, the Isabelle creek, Rush river, Plum creek, Eau Galle river and lower tributary valleys, Gilbert creek, Wilson creek and Hay river, conditions appear to be favorable for obtaining flows. The flows probably will be restricted to the lowest ground along the valleys with head not exceeding 20 or 30 feet above the level of the river adjacent. The lower sections of the valleys mentioned in Pierce

county, 5 to 10 miles above the lower end, are probably the productive portions. Farther north along the Eau Galle, and in tributary valleys of the Red Cedar, the favorable sections may be located at various places farther up the valleys.

South of the Chippewa river, flows are developed in certain sections of such valleys as the Beef and Trempealeau rivers, and it seems reasonable to believe that additional flows can be obtained in other section of these valleys, and in favorable sections of the Waumandee valley, and other tributaries. Flows should also be obtainable on low ground up the Black river, probably as far as Melrose, and up the La Crosse valley, several miles beyond their present development, west of Sparta.

In Coon Creek valley is a very productive area of artesian flows extending for 15 miles up the valley. Although no flows are at present known in the valley of the Bad Axe immediately to the south, it is reasonable to suppose that flows may also be developed some distance up this valley.

East of the Mississippi along the north side of the Wisconsin river many flowing wells have been developed within the Kickapoo and Baraboo valleys. The productive areas of these valleys may be extended so as to include the west branch of the Kickapoo, and some of the headwater tributaries of the Baraboo.

No flowing wells are known to occur in the valley of the Eagle river and of the Pine river in Richland county, although these valleys are located betwen the productive Kickapoo valley on the west, and the Baraboo valley on the east. While favorable conditions for flows may not be developed in the Eagle river valley, it seems reasonable to believe that flows may be obtained in the Pine valley, at least above Richland Centre.

South of the Wisconsin river in Iowa, Grant and Lafayette counties, no flowing wells are known except those along the Mississippi river at Cassville, in Grant county, and on the Iowa side of the river, at Dubuque. It seems very probable that conditions are not favorable for obtaining flows in either Iowa or Lafayette counties, in valleys tributary to the Wisconsin river or within the Pecatonica valley which is a very round-about tributary of the Rock river. However, conditions appear to be favorable for artesian flows with reasonably strong pressure in Grant county, within certain sections of the valleys of the Grant, the Platte and the Little Platte rivers which empty directly into the Mississippi.

Eastern Wisconsin, south of Lake Winnebago.—In eastern Wisconsin, flowing wells with source of supply in the Potsdam and St. Peter sand-

stone formations, occur at Waupun where a flow has been obtained with head of 883 feet above sea level (level of Lake Michigan is 581 feet), and farther east, near the lake at Sheboygan Falls, with head of 727 feet.

Farther south flows have been obtained at Whitewater with head of 839 feet, at Mukwanago with head of 830 feet, and at the Elm Grove Convent, west of Milwaukee, with head of 766 feet.

The maximum initial head of the flows obtained from the upper Cambrian (Potsdam) aquifer, in southeastern Wisconsin, is about 250 feet above the level of Lake Michigan, while the maximum head of flows obtained farther north, south of Lake Winnebago, is somewhat higher, about 300 feet above the lake. The flowing wells back a few miles from the shore of Lake Michigan are all confined to the relatively low lands within the valleys, and the artesian head of non-flowing wells on the upland divides is still higher than that of the flowing wells within the valleys, though flows are not obtainable in the uplands, because of the relatively high elevation of the land surface.

In a general way, it may be stated, that south of Lake Winnebago, in eastern Wisconsin, the probability of obtaining flows from St. Peter and Upper Cambrian (Potsdam) sandstone are good, dependent upon favorable local conditions, up to 150 to 200 feet above Lake Michigan, within 5 or 10 miles of the lake shore, and up to 300 feet or over, in the valleys within the higher upland divides, 30 to 50 miles west of the lake. It should be stated, perhaps, that flows from the drift and the Niagara limestone, with heads at still higher elevations than those from the sandstone occur in various parts of this region.

Eastern Wisconsin, north of Lake Winnebago.—North of Lake Winnebago, the artesian head of the Potsdam water declines relatively rapidly in going north, down the valley of the Lower Fox river and along the shore of Green Bay. At the lower end of Lake Winnebago, at Neenah, the artesian head is 760 fet above sea level, at Green Bay, 672, at Oconto, 630, and at Marinette, 614 (for respective heads above the curbs see tables on pages 77–8). The decline in the artesian head in passing down the valley, while conforming closely to the slope of the valley, has a fall much less than the valley itself, as indicated by the fact that the initial head at Neenah was 15 feet above Lake Winnebago while the initial head at Green Bay was 90 feet above the bay.

Between Green Bay and Marinette, the artesian head declines from 90 feet above the bay at Green Bay, to 50 feet at Oconto, and to 33 feet at Marinette. While the decline in the artesian head along the west side of Green Bay may be partly due to the decrease in the thickness and in the extent of the outcrop area of the Upper Cambrian sandstone in go-

ing north, the decline in artesian head is probably mainly due, to the greater flatness of the area adjacent to the bay, and the consequently less favorable condition for reinforcement of artesian pressure from a high water table adjacent to the shore.

In general, it may be stated, that north of Lake Winnebago in eastern Wisconsin, the probability of obtaining flows are good (with the exception named below) from 100 to 200 feet above the level of Green Bay, in Brown and Outagamie counties,—probably about 200 feet being the maximum head in the valleys 20 to 30 miles back from the bay, and 100 feet the probable maximum within 5 or 10 miles of the shore. Farther north, in the southeastern parts of Shawano, Oconto and Marinette counties, flows will probably not be obtainable over 100 or 125 feet above the level of the bay, probably from 50 to 125 feet above the bay, 10 or 15 mlies up the valleys leading back from the bay, and from 25 to 50 feet above the bay within a few miles of the shore.

Kewaunee-Door Peninsula.—Although it was formerly predicted that flows would be obtainable from the St. Peter and Upper Cambrian sandstones (Potsdam) for the whole of the border of Lake Michigan, subsequent developments seem to indicate that the sandstone formations are barren of artesian pressure along the lake shore, north of Manitowoc. While slight flows of about 20 feet above the level of the lake have been obtained from the Niagara at Two Rivers and Algoma, no additional flow was obtained at either of these places, in a well that penetrated through the Potsdam to the granite at Two Rivers, and through the St. Peter to the middle part of the Lower Magnesian at Algoma.

An explanation for the absence of artesian flows from the St. Peter and Upper Cambrian acquifers north of Manitowoc is offered on p. 81, three changes in the geological conditions being pointed out as unfavorable to artesian development in the peninsular district east of Green Bay, as compared with the favorable conditions developed farther south. Whatever the principal causes operative in preventing the development of flows from the St. Peter and Upper Cambrian at Two Rivers and Algoma, there is very apparently, in the peninsula east of Green Bay, a change in the geology and topography sufficient to develop conditions unfavorable for securing artesian flows. It is probable that flows may be obtained along the west shore of the peninsula, 5 or 10 miles north of Green Bay, but it is not likely that the productive area extends farther north.

Rock River Valley.—In the tributary valleys of the Rock River, flows have been obtained at Beaver Dam, as previously stated, with head 886 feet above sea level. It is reasonably certain that flows may be obtained

at still higher elevations near the summit of the divide surrounding the Rock river drainage basin. The areas of probable success are necessarily confined to the low ground within the valleys, and the available head in these favorable localities is not likely to be more than 10 or 15 feet above the curb or above the adjacent stream level, the artesian gradient following closely the gradient of the valley bottom. Local geologic and topographic features, favorable to the development of a high groundwater table in adjacent uplands, are essential requisites for the development of artesian flows at these higher elevations, and the favorable conditions should be considered as having only local, and not general application.

While it is not always possible to draw a sharp line between deep-seated surface flowing wells, as both classes depend largely on local conditions, and both often occur in the same localities, the foregoing statements have been confined to artesian wells having their source mainly in the Upper Cambrian (Potsdam) sandstone, and to a minor extent in the overlying St. Peter sandstone or Lower Magnesian limestone formations, the latter formations being drawn upon, only in the eastern part of the state. Occasionally, artesian wells have been obtained from the Galena-Platteville (Trenton) limestone where this formation is the bed rock in the valley bottoms, as in the upper part of the Fox river valley, illustrated by some of the artesian wells in Fond du Lac, but usually the source of the artesian flows in the Trenton is indirectly in the underlying St. Peter and Potsdam aquifers.

Prospecting for Surface Flows.

The surface flowing wells indicated on the general map are far more abundant and are scattered over a much larger area of eastern Wisconsin than the deeper-seated flowing wells from the St. Peter and Potsdam horizons. In the southwestern one-fourth of the state, however, within the driftless or thin drift area, the surface-flowing wells are relatively rare.

The surface artesian wells derive their flow from beds of sand or gravel, sandwiched between beds of clay within the surface formation, between the surface clay and the fractured rock below, and from within the fractured jointed rock underlying the surface formation. The fractured and jointed rock may be any formation, but it is usually the Niagara limestone, and only occasionally the Pre-Cambrian Crystalline rock. The essentials of these surface artesian flows are as follows:

1. An adequate source of water supply, which is the precipitation,

mainly in the form of rain, that falls upon and sinks into the adjacent porous uplands.

2. A retaining agent, offering more resistance to the passage of water than the well, which is mainly a bed of clay or other relatively impervious material, overlying the water-bearing sand or gravel bed, or the fractured and jointed rock.

3. An adequate source of pressure, which is mainly the weight of the groundwater table in the adjacent uplands, pressing down upon the water confined within the water-bearing strata from which the flow is obtained.

The surface flows are, therefore, local in origin and depend upon favorable underground and topographic conditions, developed within a few hundred feet to 5 or 10 miles of the well. The location of the flows is always confined to relatively low ground in valleys, or along the lower slopes of the uplands, or within the slopes of former lake basins. The available head is generally low, usually less than 20 or 30 feet, though occasionally 50 or 60 feet, above the lowest ground of the immediate locality.

Flows from the drift.—The surface flowing wells from the drift are cheaply obtained and are very serviceable. They will undoubtedly be found in certain parts of the state where not yet developed, and their areas may be extended in some cases much farther up the slopes and the valleys where already developed. No detailed statement of local areas in various parts of the state where success may be obtained is warranted. It may be well to point out, however, that the favorable areas for the surface flows in the drift, as may be inferred from the above described essentials, are necessarily located some distance below the general groundwater level of the adjacent uplands, and are confined to water-bearing surface formations of glacial, alluvial or lacustrine origin in which the water is capable of being held under hydrostatic pressure. Especially favorable places for the development of surface flows in the drift are in the sand, gravel and clay beds within the former expanded Great Lake basins and estuaries, adjacent to Lake Superior, Lake Michigan and Green Bay.

Flows from the Niagara limestone.—Flowing wells in the Niagara limestone are quite common in the general outcrop area of this formation in eastern Wisconsin. The Niagara formation has a usual thickness of 300 to 400 feet, and overlies the impervious shale beds of the Cincinnati group. The numerous fractures and open joints in the Niagara formation, combined with the impervious shale at the base, undoubtedly develops conditions favorable for artesian wells in some localities,

entirely independent of the artesian conditions developed in the overlying surface formation. The area of flowing wells about Rockfield and South Germantown, in southeastern Washington county, (see Pl. III) is a good example of conditions under which flows from the Niagara are developed. In this area, flows with maximum initial head of 30 to 60 feet above the curb, or up to 370 feet above the level of Lake Michigan, were obtained.

Many of the artesian wells in the Niagara, however, appear to depend wholly upon favorable conditions developed in the overlying surface formation as the flows are obtained at the contact of the two formations, and hence on the map (Plate I) the flowing wells in the Niagara and in the surface formations are classed together.

Flows from the Pre-Cambrian Crystalline rock.—Occasionally flowing wells with low head have been found with source of flow in the granite, slate or other Pre-Cambrian crystalline rock, the flows being usually, but not always, restricted to areas where the latter is overlain by porous drift formations. The flows from the granitic rock are dependent upon the same conditions as those developed within the Niagara, or at the contact of the Niagara with the overlying drift. The flows from the granite and other crystalline rock are of interest as a type, but are relatively rare and unimportant in occurance, on account of the generally flat slope of the crystalline area, combined with the relatively shallow depth of the fractures and joints and the consequent shallow depth of the water-bearing zone in the granite.

While predictions can be made concerning favorable areas for obtaining surface flows from the drift and from the Niagara, no predictions are warranted concerning surface flows from the crystalline rocks. On the contrary, it may be stated, that any general or systematic attempt to obtain flows, or even any considerable quantity of ordinary groundwater, from the crystalline rocks is wholly unwarranted, and drilling should very generally cease within 10 or 20 feet after reaching this formation.

Methods of Drilling for Flowing Wells.

While driven wells are occasionally used in obtaining very shallow flows, the standard drilled well is the type very generally used in drilling for artesian and ordinary groundwater wells in Wisconsin. The driven wells consist of small iron tubes, usually 1 to 3 inches in diameter, provided with a point and screen. The well points are likely to become clogged in a relatively short period, and hence this type is used only in

very shallow wells, and to a limited extent where the well tubes can be readily replaced.

The standard drilled well is the usual type in Wisconsin and is sunk by percussion of a heavy drill, usually 2 to 12 inches in diameter, lifted and dropped from a portable rig by means of power, generated by steam or gasoline engines. The drill hole is cased with iron pipe in the surface formation and soft rock, and is usually not cased in the rock.

While the special operations in drilling of non-flowing and flowing wells is much the same, certain precautions are essential in drilling a well to obtain flowing water, that are not necessary in drilling ordinary groundwater wells.

Packing and Casing.—In constructing a flowing well, it is very generally necessary to make a water-tight joint between the well casing and the rock, otherwise the water ascending from below will find an outlet outside the casing and fail to reach the surface. In some instances, also, if porous rock is penetrated below the point to which the well is cased, it may be necessary to insert casing through such porous material to prevent escape of water. In other instances when a water bed is weak, it may be protected with casing perforated to admit the entrance of water. The proper method of casing artesian wells is illustrated on page 503.

The diameter of artesian wells materially affects the yield, for the larger the diameter, the less the frictional resistance. The cross-section of a tube varies as the square of the diameter, and disregarding other factors, an 8-inch pipe would carry 16 times as much as a 2-inch pipe. Taking into account both the frictional resistance and the cross section, the discharge of a pipe has been calculated to vary as the 2.5 power of the diameter. While several small wells will yield a larger inflow than one large well, the yield of any well is controlled by the maximum diameter of the bore hole at the water-bearing stratum rather than the maximum diameter at the mouth of the well.

Records of flowing wells.—It is very important that drillers and owners of flowing wells should make and preserve the records of flowing wells drilled, as described on pages 5–7, in order that as complete information as possible may be available for the future exploration of artesian supplies in the locality.

CHAPTER V.

SPRINGS AND MINERAL WATERS

Much underground water returns to the land surface through springs or by diffused seepage into lakes, rivers, and marshes. The supply of groundwater furnished to the surface run-off by springs varies greatly. In places the discharge is very limited and the water differs but little in character from ordinary seepage water, while in the other localities the water gushes forth in small streams. At many places the water bubbles up through sand or gravel and the spring is not infrequently called a bubbling or boiling spring.

Springs, like wells, are of two classes, surface and deep-seated. The conditions giving rise to springs are in part the same as those for artesian wells. The water of a spring flows out of the ground by natural processes alone, while in a flowing well the water is made to flow at the surface through the agency of man. In the case of some springs the water may move downward and have a free zone to escape above some impervious bed, while in flowing wells the water reaches the surface only by hydrostatic pressure. Hydrostatic pressure therefore may or may not be one of the requisite conditions of springs. In every case gravity forces the spring water to the surface.

SURFACE SPRINGS.

Surface springs, or seepage springs, are usually associated with outcrops of impervious strata. In this class of springs the water escapes at the contact of an overlying porous bed with an underlying non-porous bed. See fig. 14.

Seepage springs may also occur along the contact of the drift with underlying shale or limestone, the water flowing along the impervious basement until it reaches the lowest point of escape.

Most of the springs in Wisconsin are of the surface type. Many of them have dried up, and disappeared, but many others are still yielding large quantities of water and in thinly settled districts form one of the chief sources of domestic supply. During the unusually wet years, as

in 1903, many of the springs which had formerly gone dry began flowing again owing to the unusually heavy rainfall and the consequent rise in the water-table.

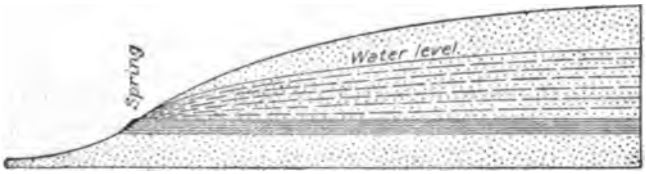


Fig. 14.—Seepage spring fed from unconfined waters in porous sand.

Deep-Seated Springs.

In the deep-seated springs, the water rises to the surface along joint planes, fissure and fault planes in bed rock. See fig. 15. The waters in the deep-seated springs are under hydrostatic pressure, confined in impervious channels or between impervious beds, and in their mode of origin are artesian springs. The temperature of the water from the deep zones of flow is more constant and, as a rule, somewhat higher than that of water from surface springs.

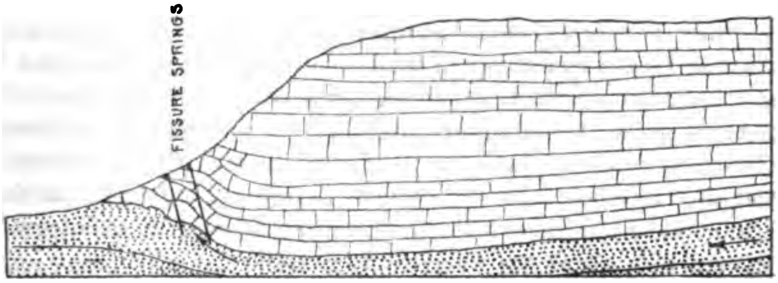


Fig. 15.—Fissure spring. The water springs from the underlying sandstone up through fissures in the limestone.

The conditions affecting the amount of groundwater available for springs are essentially the same as those already described for artesian wells.

Distribution of Springs.

Springs flow from all of the water-bearing horizons mentioned in the geological formations; but certain horizons are more important than others and give rise to a much larger number of springs. Although the various springs seem to a casual observer to be scattered promiscuously over the state, such does not appear to be the case when their distribu-

tion is studied a little more carefully. Both classes of springs above referred to, originate in the various geologic horizons and owe their distribution and occurrence to a variety of geologic features.

SPRINGS IN THE CRYSTALLINE AREA.

The springs in the crystalline area are largely due to faulting and minor displacements in the rock. The crystalline area abounds in springs which are often the chief source for domestic supply, but the springs have been very little studied and are scracely ever developed commercially. The crystalline area is so completely covered with drift that it is rather difficult to determine whether a particular spring derives its water from the underlying crystalline rock or from the overlying drift. Data that would throw light upon their source, are in nearly every case lacking and before such springs can be classified a much more extensive study is necessary.

SPRINGS IN THE UPPER CAMBRIAN SANDSTONE AND THE LOWER MAGNESIAN LIMESTONE.

The springs of note in this lower zone of water-bearing sedimentary rocks, are at the contacts of the relatively impervious and pervious shale-beds in the Upper Cambrian (Potsdam) sandstone formation and between the sandstone and the overlying Lower Magnesian limestone. The contacts are the source of supply, although the springs may not always escape or rise to the surface near them. The water often flows underground several miles from the contacts before coming to the surface. This is notably true where the surface is composed of disintegrated sandstone which allows the water ready passage.

A number of springs in the valleys rise from the Upper Cambrian (Potsdam) sandstone where this formation has been eroded so as to expose its impervious beds thus giving the water flowing along its confining walls a chance to escape.

A pecularity of some of the springs arising from the sandstone is worthy of mention. The point of escape or the location of the spring is often at the end of a projecting sandstone ridge that extends out into the valley, either along the side, or at the head of the main valley. The water follows the ridge as far as possible and finally, when no longer protected by the overlying cap, escapes to the surface, near the extremity of the ridge projecting out into the valley.

At the contact of the sandstone and the overlying Lower Magnesian limestone the water may come to the surface at the foot of a hill, where

the two formations join, and then disappear, within a short distance, only to reappear again several miles farther down where the underground channels open into the river valley. A fine example of this may be seen on Silver Creek one of the tributaries of La Crosse River. Springs may also escape at levels higher than the contact, by escaping through fissures or crevices in the limestone as illustrated by the Ilwaco springs on the St. Croix River west of River Falls. They then seem to come entirely from the limestone. The farther from the line of contact, the less numerous do the springs become, but there is usually a wide area along this contact in which the springs arise or reach the surface.

From the Lower Magnesian limestone springs arise that derive their water entirely from the limestone and are not connected in any way with those found at the junction of the sandstone and limestone. They are, however, few in number and not important.

The spring water from the Upper Cambrian (Potsdam) sandstone and Lower Magnesian limestone usually has a temperature of 48° to 50° F., is clear, sparkling, comparatively free from organic impurities, and usually low or moderate in mineral content. It contains small percentage of lime and magnesium carbonates, little iron, some silica and alumina, with small amounts of chlorides. The water has a very pleasant taste and the small amount of free carbonic acid makes it very palatable. The springs arising from the Upper Cambrian and the Lower Magnesian are not present along the eastern part of the state. (See Geological Map Plate I in Pocket) but are plentiful along those streams tributary to the Mississippi river, and especially along the St. Croix river, as at St. Croix Falls and Osceola. Although these springs are used very little at present for watering stock and general farm use, excepting those at St. Croix and Osceola, they furnish favorable conditions for developing trout ponds and for domestic supply. The waters of the springs are far superior for domestic use to much of the shallow well waters used.

SPRINGS IN THE ST. PETER SANDSTONE AND GALENA-PLATTEVILLE LIMESTONE.

The second horizon for springs, that of the middle zone of water-bearing rocks, occurs near the junction of the St. Peter sandstone and the Galena-Platteville (Trenton) limestone. The shaly impervious stratum that usually forms the base of the overlying Platteville limestone, resting upon the underlying St. Peter sandstone, divides this spring horizon into two classes, giving rise to springs either above or below this imper-

vious stratum. Under normal conditions, the water descending through the fissured limestone is caught by the shale beds and caried along their surface to some point where erosion has furnished a means of escape, thus giving rise to springs directly from the limestone flowing from above the shale. The springs from the St. Peter sandstone usually flow from the sand below the dense shaly beds. However, some of the water of the limestone may find an opening into the sandstone at some adjacent higher level and thus give rise to springs from the limestone issuing below the impervious bed, while the sandstone water under certain favorable conditions may be the source of springs that flow out above the shaly beds. As in the first horizon, there is a zone within which most of the springs are found, but a careful study of each spring is required before its exact source can definitely be stated.

A number of springs flow from different levels within the limestone, some from the contact of the Platteville and Galena beds, others from higher levels in the Galena but they do not appear to be confined to any well marked stratum. Although many are found within the Galena-Platteville water horizon, they are rather irregular in their distribution. The springs in this horizon are much less abundant than in the last mentioned Upper Cambrian-Lower Magnesian horizon but the general character of the water is very similar in both horizons. The quantity of mineral ingredients, however, in the water flowing from the Galena-Platteville limestone springs is usually somewhat greater, and the waters as a whole are harder, than the spring waters from the Upper Cambrian-Lower Magnesian horizon. They furnish water of the most excellent quality and purity, that may be safely substituted for well water in these localities in which they occur.

Springs in the Cincinnati Shale and the Niagara Limestone.

In some respects, the most remarkable horizon giving rise to springs, is that found at the upper surface of the Cincinnati shale. The water flowing from the springs at this horizon, which may be called the upper zone of sedimentary rocks, all comes from the fissured, cavernous, and decayed limestone of the Niagara formation. The direction of the flow is along the surface of the beds of the upper portion of the Cincinnati shale, either along the dip of the strata, or in some other direction that sooner or later offers an opportunity of escape. The water that flows in the direction of the dip, gives rise to flowing wells farther toward the east and is the source of many of the springs scattered over the area underlain by Niagara limestone.

The water that flows in the direction opposite to the dip of the shale strata finds an outlet along the western outcrop of the strata. The outcrop of the shale is exposed at frequent intervals along the east side of the Lower Fox and the Rock River valleys and forms a well defined zone along which the springs are located. In some localities, however, a heavy deposit of drift nearly conceals the horizon, while in others, a heavy mass of clay lies against the contact and prevents the escape of the water. The water is then forced to rise higher and seek an outlet through joints in the limestone wherever opportunity offers.

Where the glacial drift or rock fallen from the Niagara limestone cliffs above conceal the contact, the spring water may run in concealed channels down the slope, and issue some distance below its true point of escape from the shale strata. Some of these springs may, therefore, easily pass as drift springs, although their source is only indirectly in the drift. However, with a little care the line of contact itself, or its trace as indicated by the line of springs may be definitely followed. In most cases it is thus possible to determine the source of any spring in the vicinity.

In places along the east side of the Fox river valley, in the vicinity of Lake Winnebago, much of the water passing underground does not reappear in the form of surface springs, but is caught beneath a clay bed of lacustrine or glacial origin, is once more confined, and later apparently carried in underground channels directly into Lake Winnebago.

Along the east side of the Fox river valley, under the protection of the Niagara escarpment, are hundreds of springs marking this most remarkable horizon. Some of the springs are very small while others furnish sufficient power for small industries.

As mentioned before, springs which flow from various horizons within the Niagara limestone are scattered over the entire eastern district of Wisconsin. Their distribution, is irregular, depending somewhat upon the occurrence of fissures and character of the topography of the limestone. Their source is much the same as that of the artesian wells obtained from the limestone at Rockfield and South Germantown. A number of these springs have dried up since the settlement of the country and the development of agriculture, but many of the deeper-seated springs remain as strong as ever. These scattered springs from the Niagara horizon include some of Wisconsin's most famous springs, such as the noted springs at Waukesha.

The water from these springs is clear, cool and refreshing, the temperature, ranging between 46° to 48° F., remaining rather constant throughout the year. The water, from springs in the Niagara, as a

rule, is harder than other Wisconsin spring waters and contains considerable amounts of mineral matter. Within this horizon are found many travertine springs. Large specimens of the travertine have been picked up out of the streams and springs east of Fond du Lac.

Springs in the Drift and Other Surface Deposits

The foregoing springs all have their source in the bed rock. Besides these, however, there are a number of springs, both large and small, that issue from loose unconsolidated material, overlying the bed rock. This surface horizon gives rise to more springs than any other horizon considered. They are, as a class quite superficial and are subject to great variations in volume. They are more liable to contamination from surface impurities, and the temperature of the water is more varied, than from springs that issue from the rocks. They are, also, the first to be affected by any deficiency in the annual precipitation, and are controlled more or less, by merely local conditions of the drift material.

Some of the surface springs have their source in gravel and sand interbedded with layers of clay. Of this class, are those issuing under hydrostatic pressure from the junction of the porous and impervious beds of the lacustrine deposits, bordering Lake Michigan and Lake Superior. In places, a continuous line of small rivulets may be seen issuing from the junction, either below or above the bed of clay.

Other springs owe their origin to seepage and flow from loose material, which may give rise to seepage springs on the slope or at the base of hills, even if the loose material composing the slopes be of a homogeneous nature. Between these two classes there is every degree of gradation. To the latter class of seepage springs, belong the vast number of springs scattered over northern Wisconsin that help feed the numerous lakes, rivers, swamps, and marshes that abound in this region. They are, for the most part, of little importance and but seldom used. They belong to the class that will be affected most when the country is opened up to agriculture. Even at the present in the forest areas some dry up during long continued droughts.

While, in general, the seepage springs, are small and subject to local surface conditions they are, occasionally, very large. In the glaciated area, most of the springs are found along the terminal moraines. The hummocky topography and porous drift of the moraines are well adapted to catch and temporarily hold the precipitation, and finally discharge it through the springs at the foot of the range or in the flats adjacent to it, or at some other convenient point midway between the summit and the base of the drift hills.

The numerous lakes that are distributed along the important terminal moraines are largely fed by springs that pour their water into the lake either directly along the shores or through small streams that have their source in springs some distance from the lakes. This accounts in part for the clearness and purity of the water found in many of the lakes. The number of springs opening into the lake below its surface level, is not known but is probably not large, although some of the very small lakes are probably maintained from this source alone. The "Kettle Range" is lined throughout its entire extent with springs, and it has been observed that where lakes are located on either side of the main terminal moraines the springs are most abundant on that side of the lake lying nearest to the moraines. Many of the springs, besides furnishing large quantities of water, are also very constant and uniform in both flow and temperature.

Mineral Springs of Wisconsin.

To give a detailed description of springs supplying mineral waters, their location and general features is beyond the purpose of the present report. However, a few of the more important springs are mentioned in order to show the importance of mineral springs in Wisconsin. From the drift are obtained the so-called sulphur springs, the water of which varies considerably in chemical composition. The sulphur exists as sulphuretted hydrogen in the water and readily escapes on exposure to the atmosphere. Other springs are so charged with iron that they readily pass as chalybeate springs. The total mineral matter in spring waters may range from almost nothing to seveal hundred parts per million, as shown by the table of spring water analyses. (Page 124).

Mineral Waters.

All waters are mineralized, as described on pages 127 to 132, but the term "mineral waters" is made to include only those that are sold on the market as such. Mineral waters include every gradation from waters containing a very low percentage of mineral in solution to those containing a very high percentage of dissolved substances. In addition to the natural composition, some mineral waters are subjected to artificial treatment, such as the addition of mineral salts or the addition of carbonic acid gas, but so far as possible, waters that have been subjected to considerable change are excluded from this classification.

On the basis of use, mineral waters are separated into two groups,—

those sold for their therapeutic value (medicinal water), and those sold for use as drinking water (table water).

Quantity and Value.—In 1863 the first attempt was made to collect statistics of mineral waters in the United States, and since that year, Wisconsin has ranked among the first states, both in production and value. Wisconsin is generally considered the leading state in the Union in the value of mineral water and third in the quantity of mineral water sold on the market, generally ranking first in value of table waters and generally fifth in value of medicinal water. In 1911[1] the quantity of mineral waters sold in Wisconsin was 5,716,162 gallons, the value of table water being $862,965, and of medicinal waters, $93,023.

The production of mineral waters in Wisconsin for the past seven years is shown in the following table:

TABLE 20.—*Production and value of mineral waters in Wisconsin, 1907—1913.*

Year.	Springs reporting sales.	Quantity sold (gallons).	Value.
1907	29	6,839,219	$1,526,703
1908	28	6,084,571	1,239,907
1909	34	6,101,882	1,132,239
1910	36	6,400,812	974,366
1911	31	5,716,162	955,988
1912	31	6,045,719	869,495
1913	30	7,234,217	790,552

Thirty springs reported sales in 1913. There were resorts at four of the springs, which acommodated over 1,800 guests, and the water at three was used for bathing. In addition to the sales, more than 645,000 gallons were used in the manufacture of soft drinks.

Besides the quantity of water used in the manufacture of soft drinks, a large amount of water, usually artesian water, is annually used in Wisconsin in the manufacture of beer and other malt liquors. In the production of malt liquors, Wisconsin generally ranks about the 4th state in the Union, the quantity of beer, ale and porter produced in 1913 being 5,171,179 barrels, or 160,306,549 gallons. About three-fourths of the production is manufactured in Milwaukee, the water utilized being obtained from artesian wells. About 92 per cent of fermented liquors consist of water, and the quality of the product depends much upon the character of the water.

[1]Production of Mineral Waters, Mineral Resources for 1911, U. S. Geol. Survey, Pt. II, p. 1173.

The following list of 37 springs (including a few wells) have reported sales in the last 3 years, 1911–13:

List of Wisconsin Mineral Springs.

Allouez Mineral Spring Co., Green Bay, Brown County.
Arbutus Mineral Spring, Oconto, Oconto County.
Badger State Mineral Water Co., Darlington, Lafayette County.
Bay City Spring, Ashland, Ashland County.
Bethania Spring, Osceola, Polk County.
Bryant Silver Springs, Madison, Dane County.
Castalia Spring, Wauwatosa, Milwaukee County.
Chippewa Spring, Chippewa Falls, Chippewa County.
Crystal Spring, Sheboygan, Sheboygan County.
Crystal Springs, Waupaca, Waupaca County.
Elysian Spring, Prairie du Chien, Crawford County.
"Famous" Ginseng Bottling Co., Menomonie Falls, Waukesha County.
Kusche Spring, Oshkosh, Winnebago County.
"Lebenwasser" J. J. Handeln, Green Bay, Brown County.
Maribel Mineral Spring, Maribel, Manitowoc County.
Maskanozes Spring, Butternut, Ashland County.
Nee-Ska-Ra-Spring, Wauwatosa, Milwaukee County.
St. John Mineral Spring, Green Bay, Brown County.
Sheboygan Mineral Spring, Sheboygan, Sheboygan County.
Sheridan Mineral Springs, near Lake Geneva, Walworth County.
Solon Springs, Solon Springs, Douglas County.
Spring Grove Epsom Spring, Green Lake, Green Lake County.
Wilmette Springs, H. Tolfson & Son's Cooper Station, Racine County.
Waukesha Springs, Waukesha County.
- Almanaris Spring.
- Anderson's Spring.
- Arcadian Spring.
- Bethesda Spring.
- Clysmic Spring.
- Crystal Rock Spring.
- Fox Head Spring.
- Glenn Rock Spring.
- Horeb Crystal Spring.
- Minniska Spring.
- Roxo Spring.
- Silurian Spring.
- White Rock Spring.

It is quite probable that a number of spring waters are sold in various parts of the state which are not included in the list of mineral springs above enumerated. In the various tables of mineral analyses of waters of the various counties of the state, is included a large number of spring waters which have been placed on the market during the past years.

Composition. Mineral waters represent rain water which has become mineralized in its journey underground, from the point at which it entered the soil to its point of recovery at the spring. The chemical character of the soil and rocks traversed, the length of the journey, the length of stay of the water underground, the depth, as affecting tem-

perature and pressure and the general mineralization of the surrounding body of underground water are all factors influencing the character of the mineralization. Springs flowing from beds of sand and gravel, or from the sandstone, in those parts of the state where the body of underground water is relatively shallow, yield only slightly mineralized water; but springs that issue from rocks, the waters of which are in contact with deep bodies of underground water, yield more highly mineralized waters.

The mineral analyses of many of the spring waters in the above list of mineral springs are given in the following table:

TABLE 21. *Analyses of Mineral Waters.*
(In parts per million)

	Silica (SiO_2)	Aluminum oxide (Al_2O_3)	Iron (Fe)	Aluminum and Iron Oxide ($Al_2O_3+Fe_2O_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Phosphate radicle (PO_4)	Total dissolved solids
Chippew Spring, Chippewa Falls	7.3	.2	.2	....	5.5	2.2	2.0	.6	15.0	1.9	.8	.3	36
Bethania Spring, Osceola	8.7	1.3	0.8	....	70.5	28.8	31.9		185.8	15.6	37.8	tr	381
Arbutus Mineral Spring, Oconto	16.8	2.7	0.1	....	64.5	27.2	8.6	1.2	163.7	14.8	4.0	....	304
St. John Mineral Spring, Green Bay	20.0	2.5	.7	....	24.8	22.0	8.2	4.4	56.4	27.8	38.0	....	205
Bryant Silver Spring, Madison	16.6	....	....	4.3	57.8	32.0	3.4		165.8	3.7	5.2	....	289
White Cross Spring, Madison	18.0	7.0	....	....	77.8	42.0	1.9		213.5	7.6	7.0	....	375
Badger Mineral Spring, Darlington	10.4	1.1	0.5	....	59.4	45.8	4.5	.8	200.	4.	4.1	....	332
Maribel Spring, Maribel	14.0	2.1	1.4	....	46.1	27.0	4.6	2.2	141.5	2.9	7.0	....	249
Nee Ska Ra Spring, Wauwatosa	12.4	....	....	2.0	83.4	36.3	11.1		178.6	58.1	17.1	....	399
Bethesda Spring, Waukesha	12.7	2.1	0.2	....	68.2	35.2	17.7	3.5	200.8	9.6	8.0	....	358
Arcadian Spring, Waukesha	11.5	1.5	0.3	....	68.7	31.0	7.1	3.5	179.8	14.8	3.2	tr	321
Clysmic Spring, Waukesha	11.8	2.0	0.4	....	76.8	35.5	14.2	4.1	199.8	26.2	4.6	....	375
Crystal Rock Spring, Waukesha	8.1	1.5	0.2	....	56.9	27.1	19.0	15.0	149.1	35.3	14.5	tr	328
Fox Head Spring, Waukesha	16.7	7.1	tr	....	44.0	32.7	2.7	1.3	145.5	9.4	4.2	....	263
Horeb Crystal Spring, Waukesha	12.5	4.0	tr	....	73.6	34.	8.		194.5	14.3	1.8	....	343
Minniska Spring, Waukesha	26.7	1.5	0.7	....	71.3	36.3	3.9	0.6	194.3	17.7	4.9	....	358
Silurian Spring, Waukesha	12.	10.	1.1	....	67.9	33.6	14.7		186.5	3.4	19.9	....	349
White Rock Spring, Waukesha	9.1	....	0.6	....	70.7	57.2	15.9		170.6	50.1	10.5	....	385
Sheridan Mineral Spring, near Lake Geneva	15.8	0.7	0.5	....	113.6	62.3	25.2		345.6	7.7	6.5	....	578
Spring Grove Epsom Spr., Green Lake	14.	....	....	....	59.5	62.4	1.3		89.2	246.5	2.	....	475
Sheboygan Miner'l Water, Sheboygan	15.8	81.6	0.6	....	341.6	81.3	896.4	169.3	9.8	673.	1272.	....	3541

Some of the Wisconsin mineral waters are exceptionally free from mineral matter. The slightly mineralized waters, like the Chippewa Spring water, are obtained from the region of the Upper Cambrian sandstone and the Pre-Cambrian crystalline rock in the central and northern parts of the state. Some of the springs are more highly mineralized, and those of this class occur in the area of the Niagara limestone formation of eastern Wisconsin. The mineral waters from deep wells at Sheboygan and Prairie du Chien are highly charged with chlorides. The well known springs at Waukesha yield carbonate waters of only moderate mineral content.

As mineral waters are usually classified, most of the Wisconsin waters placed on the market are calcic-carbonated-alkaline waters, this type being well represented by the well-known mineral spring waters at Waukesha. While the Chippewa spring water belongs to the calcic-carbonate type, the remarkably low content of mineral solution in this water makes it an unique type by itself. The Spring Grove Epsom spring water belongs to the magnesic-carbonated-alkaline waters or epsom salt water. The Sheboygan mineral water, which is a type of salt water, belongs to the class of sodic-calcic-muriated-sulphate waters.

Use of Mineral Waters.

Most mineral waters sold are used for table waters and only a relatively small proportion for medicinal purposes. About 10 per cent of the Wisconsin product is used as medicinal water. Necessarily no sharp line can be drawn between the two classes. In general, however, the table waters are less mineralized than those sold for medicinal use.

Medicinal Waters.—Medicinal waters are generally grouped in three classes, purgative, "lithia", and sulphur waters. The first class includes many widely advertised waters, which usually contain high percentages of sulphates with much magnesium or sodium, or both, probably in the form of Epsom salts and Glaubers salts, to which they owe their distinctive properties. The "lithia" waters contain lithium, but usually in only very small quantity, and their use is generally advocated for all forms of uric acid conditions. The cures attributed to such waters are usually attributed to copious use quite as much as to the physiologic action of the lithia compound. The sulphur waters include the abundant waters drunk at various sulphur springs. They are usually not sold in bottles and therefore are not included in the statistics, but the total quantity annually consumed is very large.

The therapeutic application of water, or its use for the correction

of diseased conditions of the body, has always been recognized in scientific writings. That natural waters have curative properties seems to be indicated by the continuous and increased patronage at mineral spring resorts. Yet the claims of miraculous recovery by use of mineral waters, and extravagant statements in regard to the waters, should be regarded with considerable skepticism, because the curative properties of such waters are frequently attributed to minor ingredients that are present in comparative insignificant quantities. The physiologic effect of these minor ingredients, such as lithium, bromine, iodine, are usually overshadowed by that of other substances present in much larger quantities.

No statement can be made here concerning the medicinal value of the various ingredients of mineral water, or the quantity of such constituents required to produce physiologic reactions. Those interested in this subject will find it fully discussed in a recent paper by R. B. Dole.[1] This paper also contains a fairly complete list of references to this subject.

Table Water.—The waters sold for table use in Wisconsin include the names of many springs that have been widely published, and for which the state is famous. Table waters must be agreeably light and pleasant, and few are strongly mineralized. Many of them are artificially carbonated to make them more palatable and to make them keep better. Table waters may be divided into two classes,—the still waters sold in large bottles or barrels for households, offices and factories, and those sold in smaller packages,—quarts and pints, much of which is carbonated. The former group is largely sold for less than 10 cts. per gallon to dwellers in towns and cities where public supplies are objectionable or suspicious, and meet the demand for pure and pleasant drinking water. The latter class are mostly sold at over 50 cts. per gallon for bar, restaurant, and hotel trade, and are to be classed as luxuries rather than necessities. By reason of their high selling price the total value of the annual sales of the latter is greater than of the first group, although the quantity sold is much smaller.

The possibility of the contamination of mineral waters sold on the market should constantly be taken into consideration by the owners of springs and also by the purchasers of table and medicinal waters. If the water is obtained from a seepage spring especial caution against possible sources of pollution within the catchment area should be observed. The spring reservoirs should be protected with proper casing and extreme care should be exercised to prevent contamination in handling water in the bottling works.

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[1] "The concentration of Mineral Water in Relation to Therapeutic Activity." U. S. Geol. Survey, Mineral Resources of the U. S., 1911.

CHAPTER VI.

THE GENERAL COMPOSITION, USES, CLASSIFICATION AND TREATMENT OF WATER SUPPLIES.

Water, as it issues from underground channels, by means of flowing wells, natural springs, or as it is pumped from wells, or as surface water in rivers and lakes, is never chemically pure, but always contains various solid and gaseous compounds in solution. Furthermore, the waters from two neighboring springs, only a few feet apart, or from two artesian wells near one another very rarely have precisely the same composition. Two waters may have the same appearance yet be very unlike in taste.

Source of Matter Contained in Water.—The rain, in falling from the clouds, absorbs gases from the atmosphere, and on its way through the soil and rocks absorbs other gases and takes into solution mineral and organic material with which it comes in contact. Other matter, as bacteria, soot, various wastes of life, organic and mineral matter, are washed from the land and carried along as suspended matter in creeks and rivers. The difference in the quantities of ingredients contained in the groundwater are due to the different paths along which the water travels, the variable composition of the country rock and of the soil, the time during which the water is in contact with the rock and soil, the length of the underground channels, and the differences in temperature and pressure. After long droughts surface waters are composed largely of water from springs and are, therefore, more highly mineralized than after spring floods or heavy rains, when they are mostly obtained from rain or from the melting snow.

Materials in Solution.—The materials in solution in the surface and underground waters belong to two classes—gases and solids. The substances of either class vary widely in their solubilities and the presence of members of one class greatly affects the solvent action of the water upon members of the other. The degree of mineralization of a water varies with the solubility of the constituents of the strata, the temperature, pressure and composition of the solvent.

Water Analyses.

There are, in general, two kinds of water analyses,—the chemical or mineral analysis of water, and the sanitary analysis of water.

Sanitary Analyses of Water.—Sanitary analyses of water are of two classes, chemical sanitary analysis and bacterial sanitary analysis. A chemical sanitary analysis of water usually consists of the determination of nitrogen as free ammonia, albuminoid ammonia, nitrites and nitrates, the amount of chlorine, sulphate, iron, oxygen consumed, total solids, hardness and "alkalinity". In addition, especially in case of surface waters, observations on such physical characteristics as color, turbidity and odor are usually made. Bacterial sanitary analyses consist of the determination of the numbers of various species of bacteria, the numbers developed at certain temperatures, with special reference to the quantity of colon bacteria. It is the common practice in reporting the sanitary quality of a water supply, to make some form of a combined chemical and bacterial sanitary analysis.

Mineral Analyses of Water.—The present report, beside describing the sources of water supply, deals mainly with the chemical or mineral composition of the water supplies, the discussion of the sanitary character being reserved for some other report, to be based on the research work of sanitary chemists.

Although the amount of mineral matter dissolved in the Wisconsin waters is usually small, there is a great variety of the compounds, as will readily be seen on referring to the tables of water analyses. All of these constituents in solution are obtained directly or indirectly from the minerals in the soil and rocks through which the water passes. Some are taken in solution by the solvent action upon the rocks; others result from the interaction which takes place when solutions from various sources intermingle, while some result from the reaction of the constituents upon the chemical compounds within the strata through which the waters pass. Of no small consequence is the solvent action of the dissolved gases. Hydrogen sulphide will precipitate some of the mineral compounds in solution, thus decreaisng the amount of or entirely removing certain minerals carried in solution. On the other hand, limestone, for example, though scarcely soluble in pure water is readily dissolved in water containing carbon dioxide.

Solids.

Silica (SiO_2).—Silica is present in most waters, in only very small amounts, and is therefore generally regarded as a constituent of minor

importance. In boiler waters it is classed as an incrustant. In many of the slightly mineralized waters of northern Wisconsin, however, silica is one of the most important constituents, and while the content is very low, it forms an appreciable amount of incrustation in boilers after some time of service.

Iron (Fe).—Iron is usually present in natural waters in only very small amounts, probably as ferrous bicarbonate. In most of the mineral analyses in this report the iron has not been determined separately, but together with aluminum. As little as half a part of iron per million in water is detectable by taste, and more than 4 or 5 parts renders the water very unpalatable.

Ferric Oxides and Alumina (Fe_2O_3+Al_2O_3).—In all the mineral analyses reported by industrial chemists the iron and aluminum is determined together and reported as the oxides. In boiler waters these constituents are classed with the incrustants but form only an insignificant amount of scale. Most of the analyses show a content of only 1 to 3 parts per million of iron and aluminum oxides.

Calcium (Ca).—Calcium is the principal scale forming constituent in water. The heating of waters containing calcium bicarbonate results in the precipation of calcium carbonate. Calcium is also one of the soap consuming elements in water and is therefore the principal cause of so-called hardness in water.

Magnesium (Mg).—Magnesium is present in all waters that contain calcium. In Wisconsin waters there is usually about 50 per cent as much magnesium as calcium, but the water of some of our inland lakes contains more magnesium than calcium. In most Wisconsin waters calcium and magnesium are the predominating bases. Calcium and magnesium are very similar in their industrial effects.

Sodium and Potassium (Na+K).—In most of the analysis of this report, the sodium and potassium are not reported separately. The amount of potassium in most waters is very small, being much less than the amount of sodium. Sodium is an abundant constituent of all saline waters in the form of common salt and sodium sulphate. The salts of sodium and potassium in water are non-incrusting solids, but if present in large amounts are likely to cause foaming in boilers.

Carbonates and Bicarbonates.—Most waters contain bicarbonates rather than carbonates, but in the analyses reported by industrial chemists the results are stated as carbonates. Hence, for the purpose of this report it was more convenient, in recomputing analyses to the form of statement adopted, to report the calcium, magnesium and sodium and potassium as metals, i. e.; as Ca, Mg, and Na+K, and the carbonate as

the bivalent radicle, CO_3, although it is certain that bicarbonates rather than carbonates were present in the waters analyzed. Most of the groundwaters, and all the surface waters of Wisconsin are carbonate waters rather than sulphate or chloride waters.

Sulphates.—In Wisconsin waters, sulphates are common, but much less abundant than carbonates. The industrial quality of sulphate waters depends largely upon whether calcium is also present in considerable amount, when upon heating there is precipitated calcium sulphate which is the most objectionable incrusting solid. Sodium and magnesium sulphates are readily soluble in hot or cold waters and therefore do not form incrustations.

Chlorides.—The chlorides in Wisconsin waters occur only in small quantity and are very generally much less abundant than sulphates. Most of the high chloride waters are from deep wells or from waters that are confined to certain kinds of rock formation. The distribution of chloride waters in the state is such that it appears possible to construct a normal chlorine map of the state, which would be of much value in interpreting sanitary water analyses.

Organic Matter.—Nearly all water contains organic matter, though spring and well waters usually carry very small amounts. Surface water, however, very generally contains appreciable amounts of organic matter.

Gases.

While the gaseous content of water is generally not determined in making mineral analyses of water, nevertheless certain gases are very commonly contained in waters. In none of the analyses quoted in this report were quantitative determinations of the gases made, though occasionally the presence of certain gases are indicated by qualitative tests.

The solubility of a gas varies directly with the pressure and inversely with the temperature to which it is subjected. The gases most commonly present in appreciable quantities in water from natural source are Carbon Dioxide ($C\ O_2$), Ammonia ($N\ H_3$), Oxygen (O_2), Nitrogen (N_2), and Hydrogen Sulphide ($H_2\ S$).

Carbon Dioxide ($C\ O\ _2$).—This gas is found in many of the natural waters of this state, but is not always reported in the analyses. Usually no pains are taken to retain it in the waters sent for analyses, while in a large number of cases no record is made of the carbonic acid gas, because the parties concerned are interested only in the dissolved solids present. This gas is a valuable constituent in drinking water, making

it more palatable and stimulating the digestive organs. As a solvent, it often increases the amount of less desirable minerals taken into solution.

Carbon dioxide is derived in part from the air, where it is absorbed by the waters before they reach the ground. It also results from the reaction upon limestone of the various acidic solutions derived from the decomposition of iron pyrites. It may also be evolved by the oxidation of organic matter lying beneath the surface at various depths, as in certain Paleozoic rocks and in the vegetable accumulations of the Pleistocene deposits. The presence of an excess of free carbonic acid holds in solution an excess of mineral matter, which excess is usually deposited as soon as the underground waters reach the surface where the carbon dioxide passes off into the air.

Ammonia (NH_3).—Ammonia is frequently present in the waters, being washed out of the atmosphere by rain, leached from the soil, or is the result of bacterial decomposition of organic nitrogenous matter. In surface water it usually is a measure of pollution and when present in considerable amounts the water is generally considered unsafe for drinking purposes. However, in artesian waters, which are above reasonable suspicion, the percentage of ammonia may run high and still not indicate pollution or the presence of decaying organic matter. The ammonia in artesian waters is either carried in from the zone of decaying organic matter or from the air itself and kept from oxidation. It may also come from the decomposition of organic matter or nitrates within the rock. As stated by Prof. E. H. Smith,[1] "The extraordinary ammonia can be explained on the basis that the sulphuretted hydrogen has exerted its well-known reducing action, either reducing the higher oxidized compounds of nitrogen back to ammonia, or preventing entirely their formation." In most artesian waters the ammonia has already passed into partially oxidized nitrites or fully oxidized nitrates.

Oxygen (O_2).—No doubt free oxygen is present in all surface and groundwater, as shown by the oxidation of organic matter, but its presence is not indicated in the analyses. Whether it is present or absent in the deep artesian waters has not been determined in any of the analyses quoted in this report, but the corrosion of iron casings in wells indicates its general prevalence.

Nitrogen (N_2).—Besides the nitrogen in the form of ammonia and as nitrates and nitrites in water, the free, or uncombined, gaseous element, nitrogen, like oxygen, is readily obsorbed from the atmosphere

[1] "Artesian wells as a Source of Water Supply"—Technics Publ. Co., New York, 1893, quoted by W. H. Norton, Iowa Geol. Survey, Vol. VI, 1897, p. 361.

by the solvent action of water. In the free state, however, nitrogen unlike oxygen, is chemically inert and although all surface waters of lakes and rivers are generally saturated with nitrogen, it exerts no appreciable influence upon the character of the water.

Hydrogen Sulphide (H_2S).—Hydrogen sulphide is present in many of the artesian waters and in springs and wells of certain districts, although it is seldom reported in the analyses. This gas is probably the result of the reaction of hydrocarbonaceous matter in the strata accessible to artesian water with such alkaline sulphates as are usually present in solution in the waters, or by decomposition of some of the sulphides, either in the rock, in the solution, or in both.

Public Water Supplies of Wisconsin.

Many villages having a population above 500 and nearly all villages and cities with a population above 1500 in Wisconsin are provided with public waterworks. Public water supplies are much more convenient than supplies obtained from private wells, and there is the further advantage of abundant water and high pressure for protection from fire.

A still more important advantage of public supplies is the health of the consumers. In thickly settled communities, especially in towns without sewerage systems, a great quantity of liquid sewage soaks into the ground, some of which finds its way into shallow wells used for drinking purposes. The best and safest solution of the water problem is a carefully planned public supply.

The best source of public supplies are deep wells, wherever these are possible. In those parts of the state where granite lies near the surface and only shallow wells are available the wells should be located as far as possible from any source of pollution. In many cities surface water supplies from the lakes and rivers are drawn upon. Where surface supplies are utilized, and in all large cities, those above 40,000 or 50,000 this is probably the best source, on account of the large quantity of water required, care should be taken to prevent pollution of the supply or it should be properly purified.

When proper protection from pollution is assured for the supplies of public waterworks, it is still essential that care should be taken to prevent pollution of the waters while they are stored and before their distribution through the mains. Open reservoirs should be carefully guarded to prevent the entrance of surface waters or of sewage by underground circulation. In water mains in which the water is under pressure any defect will cause a leak outward, but where water flows by

gravity through the mains, or where suction is used a loose joint or opening may permit the entrance of contaminated water from without.

In the accompanying table of public water supplies much valuable information is given concerning the water supply systems in operation in the cities of the state. This table is taken directly from the latest, 1914, annual report of the Railroad Commission of Wisconsin. As there is constant change in the amount of pumpage and extent of service of the various water systems the statements in the descriptions of the local water supplies under the county descriptions may only approximately agree with those in the table with respect to these features. In some instances also references are made to recently developed public supplies in the local descriptions not given in the table. For revised editions of this table the reader is referred to subsequent annual reports of the Railroad Commission.

Municipal and Private Ownership of Public Water Supplies. In the table there are 201 public water supplies referred to, of which 31 are owned and operated by private companies, and 170 by municipalities. The latter are referred to as "Municipal Water Works" and the former as a company which usually assumes the name of the city in which it operates.

There are certain advantages inherent in both private and municipal ownership. The principal arguments generally accepted in favor of private ownership are as follows:

1. The officials of a private water company do not hold office by political favor, but their connection with the business is permanent and their interest in and knowledge of the details is proportionately great.

2. As a result of better business methods, the cost of running a water plant is usually less in private than in public concerns.

3. The installation of improvements by a private company is simpler and does not require the tedious city-council legislation often necessary for such expenditures in a municipal system.

4. It is to the advantage of a private company to furnish as good and as cheap a supply as possible, in order to encourage the use of the system.

On the other hand, there are many advantages in a system owned by the village or city:

1. It is not necessary in a municipal system to charge enough for the water to pay a dividend on the capital invested.

2. In private companies there is always the tendency to insist that the water is pure, no matter what the actual conditions are. In municipal supplies there is a better opportunity for knowing the actual condition of the water.

TABLE 21. A. PUBLIC WATER SUPPLIES[1] OF WISCONSIN—

Location.	Name of Company.	Source of Water Supply.	Number. Intakes	Number. Wells or springs.	Depth, feet. Of intake.	Depth, feet. Of well.
Algoma*	Municipal Water Works	Lake, Wells	1	2	20	16-1336
Alma Center	" " "	Well		1		318
Amery*	" " "	Wells		1		312
Antigo	Antigo Water Co	R. Imp. Res. and wells	2	2	4-6	25-16
Appleton	Municipal Water Works	R. Imp. Res. and wells	1	4	8	600-823
Arcadia	Arcadia El. Lt. & W.Co	Well		1		385
Ashland	Ashland Water Co	Lake, wells	1	11	23	38. 60-70
Augusta	Municipal Water Works	Well and well points		23		20-30
Avoca	" " "	Well		1		50
Baldwin	" " "	Well		1		120
Bangor	Hussa Bros. Co	Wells		2		135
Baraboo	Municipal Water Works	River, wells	1	7	8	15 12-93
Barron	" " "	Wells, River				6-8
Bayfield	" " "	Lake Superior	1		43	
Beaver Dam	Beaver Dam Water Co.	Lake and wells	1	3		300-500
Belleville	Municipal Water Works	Well		1		325
Belmont	" " "	Well		1		130
Beloit	Beloit W. G. & E. Co	Spring and wells		45		40-80
Benton	Municipal Water Works	Well		1		350
Berlin	" " "	Wells		2		480
Birnamwood	" " "	Well		1		8
Black River Falls	" " "	Creek, spring	1		5	
Blair	" " "	Well		1		12
Blanchardville	" " "	Wells		2		80
Bloomer	" " "	Wells		2		130-207
Boscobel	" " "	Wells		1		750
Boyd	" " "	Well		1		80
Bruce	" " "	Wells		2		43
Brodhead	" " "	Wells		5		76
Burlington	" " "	Wells		3		155-1,100
Cambridge	" " "	Flowing well		1		200
Cameron	" " "	Well		1		113
Cashton	" " "	Wells		2		214-240
Cassville	" " "	Well		1		1,102
Chetek	" " "	Wells		3		40
Chippewa Falls	Chip. V. Ry. Lt. & Pr. Co	Springs, well		9		9
Clear Lake	Municipal Water Works	Well		1		200
Clinton	Municipal Water Works	Well		1		960
Clintonville	" " "	Wells		6		12
Colby	" " "	Wells		2		10-22
Columbus	" " "	Wells		3		84-197
Corliss*	Wisconsin Engine Co	Well		1		300
Cuba City	Municipal Water Works	Well		1		225
Cudahy	Milw. Mun. Water Wks	Lake Michigan				
Cumberland	Municipal Water Works	Well		1		735
Darlington	" " "	Spring and wells		1		6
Deerfield	" " "	Wells		2		129-152
De Forest	" " "	Well		1		400
Delavan	" " "	Wells fed by springs		2		125-110
De Pere	" " "	Wells		5		800-1000
Dodgeville	" " "	Wells		4		130-450
Durand	" " "	Well		1		303
Eagle River*	E. Riv. Lt. & W. Co	Well, river		1		12
E. Milwaukee	Milw. Mun. Water Wks	Lake Michigan				
E. Troy	Municipal Water Works	Well		1		690
Eau Claire	" " "	Wells		103		40-70
Edgerton	" " "	Well		1		1,000

[1] Report to the Railroad Commission for the year ending June 30, 1914.

*Report incomplete.

SOURCE, PUMPAGE, PRESSURE AND CONSUMERS.—Continued.

Average daily pumpage M. gallons.	Range of ordinary pressure in lbs.	Range of fire pressure in lbs.	Purification System.	Consumers. Public.	Industrial.	Commercial.	Total.	No. of meters	Miles of distribution mains.
...	...	...	...	...	...	...	...	...	...
1	120-140	...	...	12	...	...	48	1	1.08
...	...	...	...	...	...	...	...	...	...
720	35- 44	90-110	...	142	9	761	912	26	14.29
2,560	60- 65	90-110	Covered sand filters...	4	29	2,033	2,066	722	...
40	60- 82	60- 82	...	...	...	...	150	0	3.02
1.277	20- 65	80-125	4 sand filters. covered total capacity, 4,000,000	261	51	1,906	2,218	646	30.7
...	60- 65	65- 90	...	...	...	...	101	1	2.8
16	65	65	...	...	...	...	22	22	1.18
20	37	37	...	...	...	...	168	0	2.05
9	22½	100	...	...	...	...	82	15	0.7
700	95-110	110-125	...	14	21	1,055	1,090	536	14.36
90	45	100	...	...	...	...	227	0	3.4
103	...	...	...	...	...	...	341	256	5.02
703	50- 60	100-125	...	...	13	1,357	1,370	7	16.67
20	60- 76	100-120	...	...	...	...	72	1	1.83
10	55- 60	55- 60	...	...	...	...	69	0	1.35
1,679	50- 55	70- 90	Sand filter...	48	32	2,323	2,403	2,136	28.68
10	...	...	...	...	...	...	72	1	1.55
171	48- 60	80-100	...	99	13	606	718	432	9.58
20	59- 80	90-120	...	...	...	...	31	0	.61
100	75-100	75-100	...	30	...	346	376	113	4.35
36	65- 80	65- 80	...	...	...	...	108	3	1.81
25	65- 75	65- 75	...	...	...	...	55	13	1.41
27	60	60	...	35	...	124	159	126	2.83
...	...	...	...	...	...	...	41	40	.67
10	35	40	...	...	...	...	84	0	1.20
...	60- 70	100-120	...	8	...	14	22	...	.54
332	60- 80	100-120	...	...	...	...	234	0	5.62
211	65- 70	65- 70	...	2	14	684	700	700	14.06
21	50- 60	85- 90	...	...	...	...	60	0	1.42
20	32- 38	48-50	...	...	...	...	64	0	0.57
18	18- 25	18- 25	...	...	...	...	143	17	3.69
...	70- 78	78-110	...	...	...	...	72	5	2.00
...	50	50	...	...	...	...	26	25	.7
...	40- 75	40- 75	...	...	30	1.887	1.917	203	17.36
3	40- 50	40- 50	...	...	...	...	22	0	0.30
33	60	60	...	...	...	...	167	65	4.5
15	55- 65	100-140	...	...	...	...	71	71	2.05
...	...	...	...	...	...	...	13	0	...
80	50- 65	...	...	60	1	387	448	293	7.75
...	...	...	...	...	...	...	...	...	...
21	54- 56	54- 56	...	...	...	...	208	45	1.32
...	...	...	...	...	...	...	405	405	9.05
...	35- 45	35- 45	...	...	...	...	224	224	2.80
145	55- 60	...	...	...	...	...	466	201	.93
...	55- 60	...	...	...	...	...	37	0	1.05
8	40- 50	40- 50	...	...	...	...	53	0	1.71
...	37- 50	170-180	...	...	...	...	422	423	7.2
130	...	...	...	...	...	700	700	293	11.13
51	70	70	...	...	...	...	112	112	2.43
6	65- 85	75- 95	...	...	...	...	35	35	3.2
...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	223	0	8.58
16	50- 55	60- 65	...	...	...	...	65	64	1.37
2,500	70- 80	110-130	...	29	51	2,926	3,006	2,062	42.69
131	66- 70	75-120	...	62	56	480	568	670	7.06

TABLE 21, A. PUBLIC WATER SUPPLIES OF WISCONSIN—

Location.	Name of Company.	Source of Water Supply.	Number. Intakes.	Number. Wells or Springs.	Depth, feet. Of intake.	Depth, feet. Of wells.
Elkhart Lake	Municipal Water Works	Lake	1		9	
Elkhorn	" " "	Well		1		1,050
Ellsworth	" " "	Well		1		609
Elmwood	Elmwood Water Works.	Well		1		180
Elroy*	Municipal Water Works	Wells		3		88-196
Evansville	" " "	Wells		3		12
Fennimore	" " "	Wells		2		250-800
Florence	" " "	Lake	1		27	
Fond du Lac	" " "	Imp. res. and wells	1 Res.	9		480-650
Fort Atkinson	" " "	River, wells	2	1	3-6	753
Frederick*	" " "	Well		1		84
Fox Lake	" " "	Wells		2		129-165
Galesville	" " "	Wells		3		150
Gays Mills	" " "	Well		1		200
Glenwood	" " "	Well		1		200
Glidden	" " "	River, well	1	1	6	20
Grand Rapids	Municipal Water Works	River, wells	1	M'ny	6-8	6-30
Green Bay	Green Bay Water Co.	Wells		11		850-933
Greenwood	Municipal Water Works	Well		1		30
Hartford	" " "	Wells		3		126
Hazel Green	" " "	Well		1		197
Hillsboro	Hillsboro City W. W.	Well		1		142
Horicon	Municipal Water Works	Wells		2		602
Hudson	" " "	Wells		3		350-364
Hurley	Hurley Water Co.	River	1		6	
Independence	Municipal Water Works	Wells		4		50
Iron River	Iron R. W. L. & P. Co.	Wells		15		26
Janesville	Janesville Water Co.	Imp. res. and wells		4	12	25-1,160
Jefferson	Municipal Water Works	Well		1		782
Johnson Creek	" " "	Well		1		332
Juneau	" " "	Well		1		750
Kaukauna	" " "	Wells		3		629-798
Kenosha	" " "	Lake Michigan	1		35	
Kiel	" " "	Well		1		29
Kilbourne	" " "	Wells		2		360
La Crosse	" " "	Wells		20		120
Ladysmith	" " "	River				
La Farge	" " "	Well		1		500
Lake Geneva	" " "	Wells		3		186-1,123
Lake Mills	" " "	Wells		2		380
Lancaster	" " "	Spring		1		14
Linden	" " "	Well		1		600
Lodi	" " "	Flowing well		1		257
Loyal	" " "	Well		1		30
Madison	" " "	Wells		11		150-750
Manitowoc	" " "	Wells and well points		7		18-40
Marinette	City Water Co.	River, lake and wells	2	1	5-25	765
Marshfield	Municipal Water Works	Imp. res. and wells	6	18	21	60-80
Mauston	" " "	Wells		6		150-250
Mayville	" " "	Wells		2		670-855
Mazomanie	" " "	Well points		10		25
Medford	" " "	Wells		11		40-60
Mellen	Peoples W. & Lt. Co.	Imp. res. and wells	1	Sev. S		
Menasha	Municipal Water Works	Fox river	1		12	
Menomonie	Menomonie W. W. Co.	River and wells	2	2	10	355-375
Merrill	City Water Works Co.	Prairie River	2		2	
Merrillan	Municipal Water Works	Wells		4		28
Middleton	" " "	Well		1		200
Milton Jct.	Milton Jct. Water Wks.	Well		1		200
Milwaukee	Municipal Water Works	River, Lake Michigan	2		6-50	
Mineral Point	" " "	Wells		2		60-100

*Report incomplete.

SOURCE, PUMPAGE, PRESSURE AND CONSUMERS—Continued.

Average daily pumpage M. gallons.	Range of ordinary pressure in lbs.	Range of fire pressure in lbs.	Purification System.	Consumers. Public.	Industrial	Commercial.	Total.	No. of meters	Miles of distribution mains.
22	54- 60	90-110	Sand filtration				75	63	1.54
140	45- 57	60- 80					277	277	5.42
11	45-110	45-110					126	124	2.2
	117	117					28	0	.53
140									
50	65- 75	65- 75					336	332	5.4
26	40- 80	100-120	Sedimentation				196	55	3.3
159	50- 60	100-120					148		2.54
1,133	30- 40	90-125		274	30	3,353	3,659	2,392	46.88
262	55- 65	65- 68		115	26	652	793	670	8.89
10							62	62	2.85
75	84- 93	84- 90					71	43	2.54
10	106-110						23	4	1.00
62	10- 60						96	0	1.38
15	70	70				82	86		1.12
300	75- 92	92-150					806	251	14.57
1.204	40	100	Sand filter	488	83	4.617	5,187	4.511	99.7
10	50	80					23	23	.41
191	40- 60	40- 60		3	18	599	620	620	8.95
25	30	30- 35					45	11	.36
15	20- 35	70-120					166	0	.26
36	60- 80	60- 80		2		194	196	196	6.4
598	60- 85	75-190		75	3	743	821	729	8.75
145	70-100	100-125	Sedimentation and mechanical filters				331	8	3.75
28	70- 80	80-105					82	47	1.42
50	90-100	100-125					208	0	2.75
1,164	70- 73	100-120	Sand filter	347	129	2,317	2,793	973	32.1
106	40-64	100-115					452	429	7.7
							69	69	1.82
	60- 65	60- 65					198	198	
249	30- 65	47-125		113	10	521	644	229	10.63
3,268	70- 75	80-100		39	65	4,082	4,186	3,205	46.88
	45- 62	45- 90					158	158	3.1
58	75- 90	90-135					320	319	6.
3,131	95-110	95-100		596	116	4,751	5,463	2,837	66.3
100	60- 65	60-125					231	0	2.49
36	65- 75	75- 80					41	0	1.24
136	65- 68	100		86	6	349	441	358	7.82
62	45- 60	60- 80					177	164	6.25
107	30- 38	60- 80		11	11	605	627	52	9.55
5	35- 40						48	0	.88
	80	80					219	0	4.1
19	50- 60	50- 60					42	0	.96
2,207	80- 86	85-120		585	80	5,640	6.255	5,720	75.96
1,205	65- 70	90-100		10	94	1,963	2,067	1,567	32.82
1,355	35- 45	100-110	Ten open sand filters	294	53	2,752	3.099	120	34.28
	60- 75	60-120						362	
150	80	80					223	187	5.0
42	72- 75	80- 85					272	271	5.4
4	80- 90	80- 90					31	23	1.95
20	38- 40	100-120					137	129	3.3
			One open sand filter	24	11	216	251	44	3.70
336	50- 66	100		109	26	574	709	604	13.27
268	85- 95			141	23	534	698	268	11 .39
967	40- 55	80- 95	5 mech. open sand filters, capacity, 1,500,000	198	17	1.043	1,258	46	21.32
40	50- 52	50-150					63	10	1.35
16	41	41					110	90	3.6
4	25- 80						67	27	1.5
47,913	15- 75		Use of Hypochlorite	3,818	1,745	67.592	73,155	60.374	507.91
30	40-125	40-125					179	179	

PUBLIC WATER SUPPLIES OF WISCONSIN—

Location.	Name of Company.	Source of Water Supply.	Number.		Depth, feet.	
			Intakes.	Wells or springs.	Of intakes.	Of well.
Minocqua*	Municipal Water Works	Lake and Well	1	1	20	172
Mondovi.	" " "	Well		1		415
Monroe	" " "	Wells		3		250-1,000
Montfort	" " "	Well		1		125
Monticello	" " "	Wells		3		145
Mosinee	" " "	Well		1		15
Neenah	" " "	Wells		3		410-672
Neillsville	" " "	Black River	1		10	
Nekoosa*	" " "	Springs				
New Glarus	" " "	Well		1		180
New London	" " "	River, Wells	1	3	8	200
New Richmond	" " "	Wells		6		57
No. Fond du Lac.	Sand Rock Water Co	Well		1		420
North Freedom	Municipal Water Works	Wells		1		
North Milwaukee	Milw. Mun. Water Wks.	Lake Michigan				
Oconomowoc	Municipal Water Wks.	Wells		2		750-829
Oconto	Oconto City W. Sup. Co.	River and Wells	1	6	6	318-598
Oconto Falls	Municipal Water Works	Well		1		187
Onalaska	" " "	Well		2		470-493
Oregon	" " "	Well		1		198
Oshkosh	Oshkosh W. Wks. Co.	Lake and Wells	2	8	5-19	280-960
Owen	Municipal Water Works	Well		1		30
Palmyra*	" " "					
Park Falls	Municipal Water Works	River	1		15	
Phillips	Phils.,L.W.Ht.& Pr.Co.	River	7		6	
Platteville	Municipal Water Works	Wells		2		1,002-1,741
Plymouth	" " "	Wells		4		20-458
Portage	" " "	River	3		3	
Port Washington.	" " "	Lake Michigan	1		38	
Prairie du Chien.	" " "	Well		1		42
Prairie du Sac*	" " "	Well		1		20
Prescott	" " "	Drive Wells		4		16
Racine	Racine Water Co.	Lake Michigan	1		40	
Randolph	Municipal Water Works	Well		1		300
Readstown	Municipal Water Works	Wells		1		250
Reedsburg	" " "	Wells		5		150-500
Rhinelander	" " "	River	1		12	
Rice Lake	" " "	Well		1		280
Richland Center.	" " "	Well		1		662
Ripon	Ripon Lt. & Water Co.	Spring and wells		4		12-30
River Falls	Municipal Water Works	Wells		3		400-600
St. Croix Falls	" " "	Well		1		100
Sharon	" " "	Well		1		610
Shawano	" " "	Wells		28		21
Sheboygan	" " "	Lake Michigan	3		12-46	
Shell Lake	" " "	Lake	1		18	
Shullsburg	" " "	Wells		2		275
Soldiers Grove	" " "	Well		1		254
So. Milwaukee	" " "	Lake Michigan	2		17-26	
Sparta	" " "	Wells		4		25-200
Spooner	" " "	Well		1		217
Spring Valley	" " "	Well		1		169
Stanley	" " "	Wells		2		30
Stevens Point	Stevens Point W. Co.	River, wells	1	2	10	20-30
Stoughton	Municipal Water Works	River, wells	1	3	5	37-1,010

*Report incomplete.

SOURCE, PUMPAGE, PRESSURE AND CONSUMERS—Continued.

Average daily pumpage M gallons.	Range of ordinary pressure in lbs.	Range of fire pressure in lbs.	Purification system.	Consumers. Public.	Industrial.	Commercial.	Total.	No. of meters	Miles of distribution mains.
25									
	55- 65						135	66	3.05
272	40- 70	100-130		119	20	[illegible]86	725	600	9.50
							38	0	1.07
28	50- 65	50- 65					52	52	1.63
20	56- 62	56- 62							
432	45 50	70- 95		129	28	701	858	719	14.11
90							375	375	12.5
[illegible]0	80- 85						131	123	1.73
81	60- 65	85- 95		4	4	170	178	217	7.33
125	53- 62	61- 80		42	7	223	272	271	3.33
80	25- 30	50- 85					266	143	3.49
							130	0	2.22
							331	330	8.25
114	50- 55	100-110		4	4	374	382	884	8.74
445	30- —	90-130		145	10	685	840	149	14.59
	50- 60	100-125	Stillwell Filter				59	5	2.75
	60- 65						192	84	2.95
61	48- 50	50- 80					94	11	2.0
2,424	35- 40	90-115	15 open, sed. and mch filters. Total capacity, 4,500,00.	520	91	3,330	3,941	1,188	60.34
9	40- 60						36	20	2.06
9	60- 70	100-125					44	43	1.64
250	75-100	100-110					103	0	1.61
129	80- 90	80- 90		19	12	947	978	806	15.22
110	70- 98	70- 98		72	16	543	632	592	4.43
487	60- 80	80-120	3 covered sand and sponge filters.	115	13	1,040	1,168	1	18.58
212	70- 80	100-110		4	35	462	501	501	7.75
80	122-125	122-125					113	113	14.05
15	40- 87	90-125					8	0	3.5
3,435	60- 80	100-130	Hyp. of Lime Filter	755	123	8,087	8,965	6,457	78.14
	60- 65	60- 65					57	57	1 .85
1	50						35	0	1.04
292	60- 65	60- 65					544	485	7.05
989	45- 54	100-140		163	20	879	1,062	3	15.37
330	60	60-100		86	20	630	736	485	10.66
250	66- 72			14	15	605	634	355	7.85
292	36- 54	90-120		124	8	691	823	139	11.69
239	60- 80			54	4	422	480	[illegible]6	5.16
11	75- 95	75- 95					66	65	1.54
21	60	60					241	225	6.0
90		80-100		8	4	202	214	209	6.01
3,526	40- 50	80-110		562	207	4,630	5,399	1,345	72.72
	40- 50	90-110					268	0	2.5
30	80-100	80-140					204	0	2.45
5	105	105					62	0	1.68
688	60- 90	60- 90	3 cov. gravity sand filters capacity 1,500,000.	139	14	706	859	728	8.02
298	55- 80	100-125		11	18	443	472	481	12.96
466	20- 30	30-120					287	0	2.6
18							48	0	.5
	60- 65	125					238	238	5.4
652	50- 60	65-100	Closed sand filters	173	32	690	895	231	16.41
288	60- 70	70-120		112	19	807	938	408	13.94

PUBLIC WATER SUPPLIES OF WISCONSIN—

Location.	Name of Company.	Sources of Water Supply.	Number. Intakes.	Number. Wells or Springs.	Depth, feet. of intakes.	Depth, feet. of well.
Sturgeon Bay	Municipal Water Works	Bay and wells...........	1	5	8	36-250
Sun Prairie.......	" " "	Wells.....................	......	2	......	712
Superior	Superior W.Lt. & P.Co.	Wells on beach..........	......	107	......	12-46
Thorp.............	Municipal Water Works	Wells.....................	......	2	......	25-28
Tomah..........	" " "	Wells.....................	......	4	......	30-100
Tomahawk	" " "	Springs, wells...........	......	2	......	16-21
Two Rivers.......	" " "	Wells	......	3	......	15
Union Grove......	Union Grove W. Wks....	Well	......	1	......	30
Viola..............	Municipal Water Works	Flowing wells...........	......	1	......	500
Viroqua...........	" " "	Wells	......	3	......	302-368
Washburn	Washburn Water Wks..	Lake Imp. Res..........	3	......	18	....
Waterford.........	Municipal Water Works	Well......	......	1	......	100
Waterloo	" " "	Well......................	......	1	......	120
Watertown........	" " "	Wells...........	......	3	......	760-1,032
Waukesha	" " "	River and wells........	1	5	10	1,000-1,500
Waupaca	" " "	River, lake and wells...	2	20	4	25-50
Waupun	" " "	Wells.....................	......	2	......	755-965
Wausau...........	Municipal Water Wks..	River, wells.............	1	41	10	32-135
Wauwatosa.......	" " "	Well......................	......	1	......	1,350
West Allis........	Milw. Mun. Water Wks.	Lake Michigan..........	......	......	......	....
West Bend........	Municipal Water Wks..	Well..	......	1	......	1,235
Westby*	" " "	Wells.....................	......	2	......	310-325
West Salem	" " "	Well......................	......	1	......	420
Whitehall*........	" " "	Well......................	......	1	......	216
Whitewater	Whitewater W. W. Co...	Wells.....................	......	4	......	400-800
Winter............	Municipal Water Wks..	Well......................	......	1	......	44
Withee*......	" " "	Well......................	......	1	......	140
Wonewoc..........	" " "	Well.................	......	1	......	430

* Report incomplete.

SOURCE, PUMPAGE, PRESSURE AND CONSUMERS—Continued.

Average daily pumpage M. gallons.	Range of ordinary pressure in lbs.	Range of fire pressure in lbs.	Purification System.	Consumers. Public.	Industrial	Commercial.	Total.	No. of meters	Miles of distribution mains.
149	40- 60	100-120	....	28	6	82	116	24	1.84
123	53- 63	58	....	......	......	......	......	......	5.05
2,020	45- 70	80-135	3 covered sand filters, capacity 5,000,000.	871	56	5,537	6,464	5,191	68.41
....	55- 65	100-110	....	......	......	......	91	0	1.00
....	65- 75	85-100	....	78	4	705	781	413	7.71
165	50- 60	125-130	....	50	14	570	634	24	5.3
....	52	110	Slow sand filtration........	85	20	638	743	743	10.1
25	48	48	....	......	......	......	136	0	3.3
....	85- 95	90- 95	....	......	......	......	87	0	.83
97	40- 53	40- 53	....	......	......	......	559	37	11.1
472	40-110	40-110	....	6	4	477	487	2	6.67
....	50- 70	50- 70	....	......	......	......	35	85	3.42
9	63- 67	63- 67	....	......	......	......	98	92	3.92
723	75- 85	85-110	....	199	45	1,242	1.486	1,276	21.01
746	60- 68	60- 68	....	18	14	1,801	1,833	1,900	27.46
243	50- 55	50-150	....	91	25	517	633	52	9.78
114	52- 60	52- 60	....	......	......	......	602	849	7.5
2.650	55- 60	100-120	....	......	......	......	......	109	32.48
212	45- 90	45- 90	....	......	......	......	665	652	15.75
438	....	....	....	349	15	1.344	1.708	1,367	31.5
75	40- 70	40- 70	....	......	......	......	306	302	6.1
20	35- 50	35- 50	....	......	......	159	159	22	2.63
....	30- 80	50- 80	....	......	......	......	144	141	1.70
....	60	60	....	......	......	70	70	......	......
162	70- 90	120-150	....	112	5	373	460	185	8.13
2	....	....	Sand filter........	......	......	......	16	......	.74
....	....	....	....	......	......	......	......	......	......
61	60	....	....	......	......	......	145	......	3.

3. It is not necessary, with a municipal supply, to postpone improvements until there is a sufficient increase in the receipts of the company to insure dividends on the cost of extension.

4. As the public officers hold their position at the will of the people there is a tendency for them to furnish as good a water supply as possible at a fair rate.

For these and other reasons municipal ownership of public waterworks has generally proved more satisfactory than private ownership in Wisconsin, as shown by the much larger number of municipal owned systems as compared with those of private ownership.

Uses of Water.

In judging the value of a water it is necessary to consider the supply in relation to its use, as well as its relation to other available supplies. Besides the use of water for drinking and domestic purposes, it is also used extensively in developing power by steam making in locomotives and in boilers in mills and manufacturing plants. In Wisconsin, waters are used extensively in direct manufacturing processes, in paper mills, sugar factories, breweries, tanneries, creameries, canning factories, woolen mills, soap factories, chemical works, and various other manufacturing plants. The medicinal properties of disolved minerals are supposed to give many waters special value. For every purpose the relative amounts of certain ingredients in the water determines its value. Considerable iron in a water may be harmful in an industrial process. The amount of suspended matter in a water may be very important and may determine its value for some purposes while for other purposes the importance of suspended matter may be insignificant.

Standards for Classification.—Since the value of a water depends largely upon its use, it is necessary to apply classifications dependent upon specific purposes and discuss the analyses from different points of view. It is essential to recognize that no one classification is constituted for all purposes. It is also essential to explain the classification adopted and define the usage of terms, and then apply the classification by hard and fast rules. The various classifications adopted may not be the best, but at least they will give definiteness to the descriptions of the quality of the water, assist in understanding their character, and give a better appreciation of the relative value of the various waters for specific purposes.

WATER FOR DRINKING AND DOMESTIC PURPOSES.

The requirements for a drinking water are more precise than those precribed in any other branch of water utilization. Water is necessary to the very existence of life and it powerfully affects human beings favorably or unfavorably, according to its character.

Much of the water supply of Wisconsin used for drinking and domestic purposes is from underground sources. Groundwaters from wells are usually drawn upon in the rural districts and villages, and in many of the cities having a population up to 20,000 or 30,000. The largest cities of the state draw their water supplies from the large lakes, Lakes Michigan and Superior. The Great Lakes furnish more than one-half the public water supplies of Wisconsin, being used by a total population of about 565,000. The rivers and inland lakes furnish supplies to about 85,000. Groundwater supplies from deep wells and shallow wells supply a total city population of about 460,000, and a rural population of about 1,225,000. (Estimated from the census of 1910.)

To be wholly acceptable as a domestic supply, water should be free from suspended matter, color, and odor, and fairly cool when it reaches the consumer; it should be free from disease-bearing germs; and it should be low in dissolved mineral matter. The nearer a water approaches these conditions, the more satisfactory it is.

PHYSICAL QUALITIES.

Suspended matter in water used for domestic purposes often causes stains in clothes and bad odors. The occurence of the bacteria Crenothrix, forming a filamentous growth in water containing considerable iron gives the water an unsightly appearance, and causes rusty stains on clothes. Odors may be caused by various conditions, a principal cause being the content of free hydrogen sulphide (H_2S) in the water. The presence of iron in Wisconsin water in sufficient quantity to be objectionable is known to occur in only a few supplies. Well waters if properly cased are generally free from objectionable physical qualities, whereas, surface waters from the lakes and rivers are likely to contain sufficient suspended matter to be very objectionable.

BACTERIOLOGICAL QUALITIES.

Before a water is used for drinking or domestic purposes there should be reasonable certainity that it is free from disease-bearing germs. The

disease germs most commonly carried by water are those of typhoid fever. The bacilli enter the water from some place infected by the discharge of persons sick with the disease, and while the germs cannot live long in the water, they persist in the fecal discharge and continue to infect the water. Wells should therefore be so located and constructed that infected waters cannot enter them (See under contamination of groundwater wells, pages 59 to 62).

Chemical Qualities.

The amounts of dissolved substances in water used for drinking and domestic purposes depends much on their nature. Not more than mere traces of barium, copper, zinc or lead are permissable, as these substances are poisonous. However, these constituents are so rare in water that tests for them are not usually made. Any constituent, present in amounts sufficient to be perceptable to the taste, is objectionable. Iron is often present in water in sufficient quanity to be detected by the taste. Only two parts per million of iron makes water unpalatable to many people. Iron in small amounts also causes trouble by discoloring wash bowls, and in producing rusty stains on clothes. Waters containing much iron cause an inky black compound with tannin to form in tea and coffee. Four or five parts per million of hydrogen sulphide are objectionable to the taste, and this constituent also corrodes kitchen utensils. Only a few well waters of Wisconsin contain sufficient hydrogen sulphide to be objectionable.

Small amounts of silica and aluminum are present in all waters, but have no special significance in relation to drinking and domestic supplies. The alkali metals sodium and potassium, are usually low in Wisconsin water supplies, and therefore not of much significance in relation to domestic supplies. However, waters high in chlorides are very generally also high in sodium and potassium, and approximately 250 parts per million of chlorine make waters taste somewhat salty, and less than this amount causes corrosion.

In regions like Wisconsin, where the chlorine content runs as low as 5 to 10 parts per million in normal waters, the amount of chlorine may be taken as a measure of contamination by animal pollution. In only a comparatively few places in the state are there brackish or saline waters, and these, in nearly all cases, are found in waters whose source is in deep lying rocks, some distance below the surface.

Salt Waters.—The distribution of salt water in Wisconsin is described more fully in another place, page 172. In this report waters ranging from 250 to 500 parts per million of chlorine are called salty, or brack-

ish, and the term "salt water" is confined to those waters containing over 500 parts per million of chlorine.

Because of the fact that the content of chlorine in most normal waters is relatively low, the establishment of isochlors, or lines of equal chlorine, in Wisconsin is entirely practical and would be of much value in interpreting the chemical sanitary analyses of waters from various parts of the state.

Hard and Soft Waters.—Calcium and magnesium, "lime and magnesia", are chiefly responsible for what is known as the hardness of water. This undesirable quality is indicated by the increased consumption of soap and by the formation in kettles of scale composed almost entirely of calcium and magnesium carbonates and calcium sulphates. In washing, sufficient soap must first be used to precipitate these salts before lather is produced. Hardness, therefore, is measured by the soap consuming capacity of a water expressed as an equivalent of calcium carbonate ($Ca\ CO_3$). The hardness can be computed from the amounts of calcium and magnesium in a water, as determined by the mineral analysis, or it can be determined by actual testing with a standard soap solution.

The hardness of waters is of two kinds,—temporary and permanent. Temporary hardness is due to the presence of bicarbonates of calcium and magnesium, and most of it can be removed by decomposing these salts by boiling the water and precipitating the normal carbonates. Permanent hardness is due to sulphates, chlorides and nitrates of calcium and magnesium, and these salts are held in solution, and can be precipitated only by adding certain chemical compounds, usually soda ash (sodium carbonate), to the water.

The general meaning of the terms "hard" and "soft" waters is variable and depends upon local usage, as determined by the relative degree of hardness of the water in different regions.

In New England, for instance, waters considered soft usually have less than 100 parts per million of total hardness. In Indiana, Illinois, Iowa and Kansas, however, it would be difficult to find water with a total hardness of less than 100 parts per million, and yet many waters in the latter states are called soft. This illustrates the uncertain significance of general descriptive words in classifying waters, and emphasizes the need of defining the exact meaning of such terms.

The general understanding of the terms "soft" and "hard" water in Wisconsin appears to be much the same as in New England, and the general usage, therefore, appears to conform fairly well with the scientific requirements. For the present report, therefore, it seems advisable

to adopt the following classification of waters with respect to hardness, which is much the same classification as that used by the U. S. Geological Survey[1] in discussing analyses:

Classification of Water with respect to Hardness.

Total hardness as $Ca\ CO_3$ (Parts per million.)		Classification.
Not less than.	Less than.	
....	50	Very soft,
50	100	Soft.
100	200	Medium hard.
200	300	Hard.
300	....	Very hard.

In the tables of mineral analyses of the separate county descriptions, the total hardness can be computed with a sufficient accuracy from the calcium and magnesium as follows: Total hardness as $Ca\ CO_3 = 2.5\ Ca + 4.1\ Mg$. So far as possible this classification is followed in the usage of the above terms relative to hardness of the Wisconsin waters. In accordance with this classification most of the waters of Wisconsin are hard waters. In central and northern Wisconsin, are many very soft and medium hard waters, while in the eastern part of the state are very hard waters. The water of Lake Superior is a very soft water, while that of Lake Michigan is a medium hard water, being very near the dividing line between soft and medium hard water as classified in the above table.

Waters of High and Low Mineral Content.—The classification of water in respect to mineral content is useful in determining the value of a water for domestic use. Waters of low or moderate mineral content could be accepted for drinking and cooking if they are also low in iron, below 1½ parts per million of Fe. Waters very high in mineral content will be unfit for drinking purposes, as such waters are usually brackish or salty. Waters of high mineral content might give trouble in cooking, although those with content up to 1,000 or 1,200 parts per million could be used if no better supply is available.

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[1] R. B. Dole, personal communication.

Classification of waters with respect to mineral content.

Total solids. (Parts per million.)		Classification.
Not less than	Less than	
....	150	Low.
150	500	Moderate.
500	2,000	High.
2,000	....	Very high.

Most waters of Wisconsin are either low or moderate in mineral content. Only a few well and spring waters are very high in mineralization.

WATER FOR BOILER USE.

The chief industrial use of water is steam making. The customary way of interpreting the value of water for boiler use is based on its tendancy to cause the formation of scale, and to cause corrosion and foaming.

FORMATION OF SCALE.

The most common trouble is formation of scale, the deposition of mineral matter within the boiler shell. When the water is heated and evaporated in a steam boiler, some of the mineral matter is thrown out of solution and solidifies on the flues or crown sheets, or within the tubes. The scale or incrustation includes practically all the suspended matter, or mud; the silica, probably precipitated as silica ($Si\ O_2$); traces of iron and aluminum; calcium appearing principally in the form of carbonate and sulphate; and the magnesium, principally in the form of the oxide, but partly in the form of carbonate. Calcium and magnesium are the principal bases in the scale forming salts, making up 80 to 90 per cent of the scale in most Wisconsin waters. If the magnesium and the sulphates are comparatively low, or if the suspended matter is comparatively high, the scale is soft and bulky and may be blown or washed out from the boiler in the form of sludge. On the other hand, if the water is free from suspended matter and high in magnesium and sulphates, a compact hard scale is formed, nearly as dense as porcelain, which offers great resistance to the transmission of heat and therefore causes great waste of fuel. The value of a water for boiler use, there-

fore, depends not only on the amount of scale produced, but also on the physical structure of the scale.

The limits for the classification of water in parts per million, in respect to scale-forming ingredients, are shown in the following table:

Classification in respect to scale-forming ingredients.

Probable Scale—forming Ingredients (Parts per million.)		Classification.
Not less than.	Less than.	
....	90	Good.
90	200	Fair.
200	430	Poor.
430	680	Bad.
680	....	Very bad.

This classification [1] is the one offered by the committee on water service of the American Railway Engineers and Maintenance of Way Association, reduced to statement in parts per million. These limits must be interpreted liberally in practice, because of the comparative hardness of the incrustation. Stabler's[2] method for calculating the amount and character of scale likely to result from use of a water, are given as follows:

$$A = .008333Sm + .00833Cm. + .0107Fe + .0157Al + .0138Mg + .0246Ca.$$
$$B = Sm + Cm + 1.3Fe + 1.9Al + 1.66Mg + 2.95Ca.$$

A represents pounds of scale per 1,000 gallons of water and B (computed from the preceding formula) represents parts per million of scale. Sm, Cm, Fe, Al, Mg, and Ca represent, respectively, the amounts in parts per million of suspended matter, colloidal matter (silica plus oxides of iron and aluminum), iron, aluminum, magnesium, and calcium in the water. In this formula Ca should not exceed $.668CO_3 + .328HCO_3 + .417SO_4$, in which CO_3, HCO_3, and SO_4 represent, respectively, the amounts in parts per million of the carbonate, bicarbonate, and sulphate radicles present in the water as such excess would not be precipitated. It is sometimes uncertain whether iron and aluminum are in solution or in colloidal state, but in applying these formulas to Wisconsin ground waters little error is introduced by assuming that Cm equals silica only. If it is desired to compute the scale-forming ingredients of waters, whose analyses in this report give no values for

[1] Proc. Am. Ry. Eng. & Maint. of Way Assn., Vol. V, 1904, p. 595.
[2] Eng. News, Vol. 60, 1908, p. 355. Also U. S. Geol. Survey Bull. 274, p. 176.

silica, iron or aluminum, Cm may be taken as 10 and Fe and Al as zero, without introducing great error. In clear waters Sm would of course be zero; consequently for most Wisconsin ground waters the amount of scale may be estimated practically from the figures representing silica, calcium and magnesium.

In the following Stabler formula, C represents the amount of hard scale in pounds per 1,000 gallons of water and D the same in parts per million, recomputed from the C formula; SiO_2, Mg, Ca, SO_4, Na, and K represent the respective amounts in parts per million of silica, magnesium, chlorides, sulphates, sodium, and potassium. If the alkalies are not separated, the figures representing sodium and potassium together and computed as sodium may be used with 2.7Na coefficient in place of the last two terms of these formulas.

$C = SiO_2 + 1.66Mg + (1.92Cl + 1.42SO_4 - 2.95Na - 1.74K)$.

The ratio (b) between the amount of hard scale and the total amount of scale is an index of the probable hardness of the scale, expressed thus:

$$b = \frac{A\ B}{C\ D}$$

If b is not more than 0.25 the scale may be classified as soft; if between 0.25 and 0.5, as medium; and if more than 0.5, as hard. For other formulas and the comments on those quoted the original article should be consulted.

The importance of scale formation and of means of preventing or reducing it in boilers, may be judged by considering the effect of a hard water like the Madison city artesian water, which is about the average composition of the water in the Potsdam and St. Peter sandstone, as well as that in the Lower Magnesian limestone of the state (see p. 177). In such waters, under ordinary usage in boilers without condensers, it would form about 2.5 pounds of scale in 1,000 gallons of water. Besides the increased fuel consumption caused by this deposit, the scale itself would amount to nearly a ton in a 1,000 horsepower system for every seven working days, and this mass would have to be shoveled, scraped, and hammered from the inside of the boiler.

The State Capitol Power and Heating Plant uses Monona Lake water, taken at depth of 8 feet where the lake is 16 feet deep. No complete analyses of the Monona lake water is available, but it probably closely resembles the Mendota Lake water in mineral content (see table of analyses page 299) and is much lower in incrusting solids than the Madison City artesian water. A water softening plant was recently installed at the Heating Plant and Supt. J. C. White estimates the saving

due to the treatment in using about 48,000 gallons daily to be about $500 annually over and above cost of the treatment, including interest on the investment..

The medium hard water of Lake Michigan, which is taken as the standard of comparison in the testing department of both the C. & N. W. Ry. Co., and the C. M. & St. P. Ry. Co., would form only about 1.04 pounds of scale in 1,000 gallons. The water of Lake Superior, which is a very soft water, contains less than 0.50 pounds of incrusting solids in 1,000 gallons.

CORROSION.

Corrosion not only affects the iron of boilers when water is heated within them, but it is also a factor of great economic importfiance in the cold water of iron pipes in water systems. The corrosion under all conditions is largely influenced by the character of the water.

The corrosion which takes place in water pipes is of various kinds, tuberculation being an important type of action. This tuberculation not only deteriorates the pipe but it likewise decreases the efficiency of the pipe by interfering with the flow of water. The inadequacy of many water systems is due to this accumulation.

The author is indebted to Prof. C. F. Burgess for the following resume concerning the corrosion affecting boilers:

"Corrosion as it affects boilers may have various characteristics dependent not only upon the qualities of water but upon the types of boilers and methods of operation. The corrosion may be general over a large part of the surface, or it may be localized in the form of pits. In some cases the pitting may take the form of tuberculation in which an adherent quantity of rust or iron compound builds up over the corrosion spot, forming mounds of considerable dimensions. In the locomotive type of boilers, grooving of the tubes is of frequent occurrence, this taking the form of a circular rim of corrosion of the tubes inside of the crown sheet. The corrosion may develop primarily on the bottoms of the boilers and where the heat is most intense, or in other cases it may be most marked at the water line and around the bolt heads, rivets and stays. That the constituents of the feed water may have an influence on the kind of corrosion is shown by the fact that some water may cause the most marked corrosion on the sides and crown sheets of boilers, while other kinds of water may have the greatest influence on the tubes.

"Corrosion or pitting is a result of galvanic action and controlled by the nature of the impurities in the water. Among the substances which

promote corrosion most rapidly are acids, hydrogen sulphides, dissolved oxygen, and such dissolved salts as produce acids upon heating.

"Numerous theories have been advanced to explain corrosion phenomena and among the leading authorities there is a wide variety of opinion. An interesting and valuable compilation of theories and data on corrosion is "The Corrosion of Iron and Steel" by J. Newton Friend.[1] One important subject of controversy is whether the dissolved carbonic acid is an important factor affecting corrosion. The evidence on this point is contradictory.

"On the most generally accepted electrical theory of corrosion the non-uniformity of the iron, caused not only by impurities but by differences of physical conditions, such as strain, porosity, and the like, set up galvanic couples. The iron being the positive element acts as the anode and liberates hydrogen on the electronegative portions. This hydrogen acts as a polarizing material or as a retardent to the further action, but any substance in the water which will remove this hydrogen will accelerate the action. Dissolved oxygen will readily attack the hydrogen as will also various other oxidizing agents. It is in an indirect way, therefore, rather than by direct solvent action, that the substances in the water affect corrosion.

"While some materials accelerate corrosion, others may retard it and depending upon this fact there are various meritorious methods of treating boiler water. Among the retardents of corrosion are soluble carbonates.

"There are so many factors influencing corrosion that a formulation of definite data to show the corrodibility of water cannot be made. Attempts in this direction, however, are illustrated by the interesting analysis given by Stabler."

It is very desirable in investigating the industrial value of a water to determine from the analysis of a water whether it is likely to be corrosive or not, but it is evident that the problem is somewhat complex.

According to Stabler[2] the following formula may be used to indicate whether a water is corrosive or not. c the coefficient of corrosion is computed thus:

$$c=1.008\ (rH+rAl+rFe+rMg-rCO_3-rHCO_3)$$
$$=H+.1116Al+.0361Fe+.082Mg-.0336CO_3-.0165HCO_3$$

In this formula r is the "reaction coefficient"[3] of the respective radicles with which it is associated and the reciprocal of the equivalents

[1] The Corrosion of Iron and Steel, J. Newton Friend, Longmans, Green & Co., 1911.

[2] Water Supply Paper, U. S. Geol. Survey, No. 274, p. 175.

[3] For definition of "reaction coefficient" and discussion of the formula, see H. Stabler, U. S. Geol. Surv. W. S. Paper No. 274, pp. 165–182, and Eng, News, Vol. 60, 1908, p. 355.

of those radicles; H, Al, Fe, Mg, etc., are the weights of these substances in parts per million as determined by the analysis.

In interpreting the value of c the fact that calcium carbonate may be precipitated on boiling should be taken into consideration, since this carries out of the system the carbonate radicle CO_3 with which the hydrogen may unite to form carbonic acid. Assuming a maximum precipitation of calcium carbonate and a minimum action upon the same, the effect of the carbonate radicle in the above formula to counteract corrosion will be reduced by 1.008 r Ca, or 0.503 Ca.. With these considerations three classes of waters with respect to corrosion may be distinguished as follows:

(1) Corrosive. If c be positive, the water will certainly corrode the boiler.

(2) Noncorrosive. If c+.0503 Ca be negative, no corrosion will occur on account of the mineral constituents in the water.

(3) Semicorrosive. If c be negative, but c+.0503 Ca be positive, corrosion may or may not occur, the probability of corrosive action varying directly with the value of the expression c+.0503 Ca.

There is reason to believe also, as stated by Burgess, that corrosion is facilitated by other conditions, such as the development of electrolytic action upon the metallic iron. Once the action of corrosion or rust is started, it is likely to continue and spread at that place producing a nodule of rust under which is a pit in the metal. A common illustration of this action of rust is shown by knife blades and other steel tools that remain bright as long as they are free from rust, but as soon as rust is developed the action will continue in spite of all ordinary attempts to prevent it.

Foaming.

Foaming is the formation of masses on the surface and above the surface of the water in boilers and it is intimately connected with priming, which is the passage of water mixed with steam from the boiler. Foaming results when the free escape of steam from the water is prevented. It is usually due to the organic matter in suspension, but a very common cause also is an excess of dissolved substances in the water, either from original sources or where the water has become very concentrated by the use of treated feed water and continual evaporation. The dissolved substances increase the surface tension and reduce the ease with which the steam bubbles break.

The foaming tendency is commonly measured by the content of alkaline salts in solution plus the organic matter, since these constituents remain in solution in the boiler water. Nearly all substances dissolved in the water, as well as the suspended and organic matter, increase the foaming tendency to a variable degree, and the exact calculation, therefore, of this tendency is not a simple matter. It is the usual custom to attribute foaming to the sodium and potassium salts and the organic matter because these substances are highly soluble and their relative importance in different waters is easily determined from analyses. According to Stabler[1], the expression 2.7 Na (Sodium) + 2 K. (Potassium) will represent the sodium and potassium salts generally within 5 per cent and always within 15 per cent. In most of the analyses in this report the sodium and potassium salts are determined together, and in transforming the statemenct of the analyses in theoretical combinations, in grains per gallon, to basic and acid radicles in parts per million, the molecular weight of sodium was used as if no potassium were present, because potassium occurs usually only in very small quantity as compared with sodium. For the general purposes of this report the expression 2.7(N+K) plus the organic matter may be used to calculate the foaming constituents. It will correspond closely to the "non-incrusting solids" usually estimated from the hypothetical combinations, and is sufficiently accurate for practical use.

The limits of classification in respect to foaming ingredients, as suggested by R. B. Dole[2], may be summarized as follows:

Classification in respect to foaming ingredients.

Probable foaming constituents (Parts per million.)		Classification.
Not less than.	Less than.	
....	70	Very good.
70	150	Good.
150	250	Fair.
250	400	Bad.
400	....	Very bad.

To a very large extent Wisconsin waters are either very good or good in their classification with respect to foaming ingredients. It is usually only in the highly mineralized waters of relatively rare occurrence that bad or very bad foaming waters occur. The bad foaming waters are

[1]Water Supply Paper, U. S. Geol. Survey, No. 274, p. 172.
[2]Statement from correspondence.

mainly confined to the eastern part of the state, though they are also of isolated or erratic occurrence in other parts of the state. Some soft waters of moderate mineral content, in Kenosha county, are sufficiently high in the alkalies (pp. 400–1) to be classed as fair or bad with respect to foaming ingredients. Surface waters from the lakes and rivers, high in organic matter, will cause excessive foaming.

Remedies for Boiler Troubles

The remedy for troubles caused by substances in bad boiler waters is the treatment of supplies before they enter boilers. Among the important methods of treatment is the preliminary heating of a feed water to reduce the dissolved gases. This may be done in an ordinary heater under pressure, but preferably under a partial vacuum. Since dissolved oxygen is an important accelerator of boiler corrosion, the analysis of a water for boiler purposes should recognize this factor. The amount of oxygen depends to some extent upon the depth from which the water is secured and it is also influenced by the method of pumping. The air lift system for example, which has a somewhat extended use, increases the amount of dissolved oxygen in the water.

When treatment of the water cannot be given there are various ways of partially reducing the injury. Low pressure large flue boilers are frequently used to reduce the trouble caused by bad water with high scale-forming ingredients. "Blowing off" is a practical way of preventing foaming, particularly in locomotive practice.

Boiler Compounds.—Boiler compounds are widely used in regions where hard waters are abundant, but treatment within the boiler should generally be given only when it is impossible to purify the supply before it enters the boiler. Many substances have been recommended for such use, but only a few have proved to be economical. Soda ash, the commercial form of sodium carbonate (Na_2CO_3) and lime (CaO) are the most valuable substances of this character. The proper amount and kind of boiler compound to be used is a question to be decided for each water from its chemical composition and the style of the boiler. The nature and reaction of various boiler compounds have been discussed at length in various publications[1], and it does not appear to be advisable to enter into details in this investigation.

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[1]Cary, A. A., The use of Boiler Compounds: Am. Machinist, vol. 22, pt. 2, 1899, p. 1153.

Palmer, Chase, Quality of the Underground Waters in the Blue Grass Region of Kentucky: In Water Supply Paper U. S. Geol. Survey No. 233, 1909, p. 187.

Stabler, Herman, The Mineral Analysis of Water for Industrial Purposes and its Interpretation by the Engineer: Eng. News, vol. 60, 1908, p. 355.

WATER FOR OTHER INDUSTRIAL USES.

The use of water in the various industries cannot be discussed at any length in a report of this nature. It is desirable, however, to point out the fact that for each specific purpose the influence of the dissolved substances in the water should be thoroughly understood. The water used in every industrial plant should be analyzed and otherwise investigated and the quality of the supply, so far as it effects the product, should be thoroughly understood by those in charge of the manufacturing processes.

The ingredients of natural waters affect the manufacture of many articles. In paper and pulp mills, dyeworks, canning factories, pickle factories, distilleries, breweries, woolen mills, starch works, sugar factories, glue factories, soap factories, chemical works, tanneries, creameries, and many other manufacturing establishments, water becomes a part of the product or is essential in its manufacture. A principal function of water in many establishments is that of cleansing or as a vehicle for other substances, and as such the supply should be free from color, odor, suspended matter, microscopic organisms, especially bacteria from sewage, and fairly low in dissolved substances, especially iron. Water used in the making of beverages, starch, dairy or meat products, or wherever it forms a part of food materials, should be hygienically acceptable.

Effect of Free Acids.—Free mineral acids, such as sulphuric and hydrochloric acid, usually present only in polluted waters, are especially injurious in paper and pulp mills, bleacheries and dyeworks, and generally require purification.

Effect of Suspended Matter.—Suspended matter, consisting of material of mineral, vegetable and animal origin, and mainly occurring in surface waters, is objectionable in all processes in which water is used for washing or comes in contact with food material. Water should be freed from suspended matter before being used for laundering, bleaching, wool-scouring, paper-making, dyeing, starch and sugar-making, butter-making, brewing and distilling, and other similar processes.

Effect of Color.—Color in water is objectionable in water for use in the manufacture of fabrics, such as paper-making, and also in bleacheries and dyeworks.

Handy, J. O., Water softening; Eng. News, May 26, 1904, p. 499.
Davidson, G. M., the C. & N. W. Method of Water Treatment: Proc. Western Ry. Club, vol. 15, No. 6, Feb. 17, 1903.
Booth, W. H., Water-softening and treatment, London, 1906.
Collet, Harold, Water Softening and Purification, London, 1896.
Christie, W. W., Boiler Waters, New York, 1906.

Effect of Iron.—Iron is a very undesirable constituent in waters, and even if it occurs in comparatively small quantities the water must be purified. Waters containing iron become turbid on exposure to the air. Such waters develop a growth of iron bacteria, *Crenothrix* that interfere in many industrial operations. Waters that contain iron as low as 1 to 2 parts per million have to be purified before being used industrially. Iron is especially objectionable in paper mills, dyeworks, tanneries, breweries, and creameries, and in many other industries, by discoloring the manufactured product. In some Wisconsin waters iron occurs in sufficient quantity to be objectionable.

Effect of Calcium and Magnesium.—Calcium and magnesium are similar in their industrial effects. These constituents are present in all waters in comparatively large amounts and are largely the cause of hardness in waters. In Wisconsin waters they form the predominating basic constituents. In all boiling processes some calcium and magnesium compounds are precipitated on whatever is boiled in the water, and this deposit may interfere with later operations. They are a cause of waste, as they decompose equivalent amounts of many chemicals employed in various industrial processes. The calcium and magnesium content of waters render an important effect in the processes of manufacture of paper, pulp, distillery and brewery products, and in soap factories and dyeworks.

Effect of Carbonates.—Carbonates occur in the water mainly combined with carbonic acid in the form of bicarbonates. In the table of analyses, however, it is stated as the carbonate (CO_3). If hard waters are boiled, the bicarbonate is decomposed, free carbonic acid is given off, and the greater part of the calcium and magnesium is precipitated as carbonate. For this reason these carbonates in water give it the quality of "temporary hardness" and hence such waters are generally more desirable in many industrial processes than waters high in sulphates.

Effect of Sulphates.—Calcium and magnesium sulphates in water cause "permanent hardness", as boiling does not precipitate these sulphates, or at most only small amounts of calcium sulphates. Hard waters with sulphates predominating are desirable in tanning heavy hides, because they swell the skins, exposing more surface to the action of the tan liquors. Sulphates, on the other hand, interfere with crystallization in sugar-making, causing a larger amount of sugar to remain in solution in the mother liquor. High calcium sulphate is also objectionable in canning peas and string beans.

Effect of Chlorides.—High chlorides in waters are generally accompanied by high sodium and potassium content. Appreciable amounts of chlorides are injurious in many industrial processes. Wisconsin waters high in chlorides are of relatively rare occurrence, and hence, troub-

les due to chlorides can usually be readily obviated by securing unobjectionable supplies. The content of chlorides in shallow-well waters, however, should be closely scrutinized, as the amount, if relatively high, may be a fair index of the amount of pollution. Chloride waters have a deleterious effect in tanning by causing the hides to become thin and flabby. Chloride waters effect the quality of sugar, and effect the growth of yeast, and the germination of the grain in the preparation of alcoholic beverages. The only effective way of removing chlorides in water is by distillation.

Effect of Organic Matter.—Water containing organic matter that comes in contact with food products should be purified before being used. If the organic matter is due to sewage pollution it is dangerous. Care in this respect is particularly necessary in creameries, cheese factories, slaughter houses, canneries, pickle factories, breweries, sugar factories, and starch works. Organic matter, not only may produce disease, but it may cause decomposition in fabrics manufactured by the use of such water.

Effect of Other Substances.—Silica and aluminum are usually not present in sufficient quantities in water to be objectionable in industrial processes, and the same is generally true for the alkalies, sodium and potassium.

Purification of Water Supplies.

Purification of water supplies is the removal or reduction in amount of objectionable substances in the water. It is practiced for the purpose of rendering supplies safe and unobjectionable for drinking and to reduce the amount of dissolved minerals injurious to boilers, or other machinery, or to manufactured products.

The most important purification plants are those installed for the purpose of making surface waters pure and safe for drinking. The removal of bacteria causing disease, and the removal of turbitity, odor, taste, and iron, are the principal requirements in the purification of a municipal supply. The usual methods of purification are slow filtration through sand, and rapid filtration after coagulation, both methods being combined with processes of sedimentation. The first method is known as slow sand filtration, and the second, as mechanical filtration. The efficiency of these filters stated in percentage of removal of bacteria should be as high as 98 and often reaches 99.8 per cent.

Slow sand filtration consists of filtering the water downward through a layer of sand of such thickness that the removal of all suspended matter is accomplished. The filter consists of a water-tight basin, on

the bottom of which perforated tiles are laid in the form of a grid, over which is a one-foot layer of gravel graded in size from bottom to top, and over the gravel is a layer of sand 3 to 4 feet in depth. When the water is applied on the surface it passes through the sand and gravel and flows away through the underdrain. The filters require cleaning at intervals, depending upon the amount of impurities in the water. Filters have been installed in a number of Wisconsin paper mills.

Surface waters are usually screened of all coarse material, such as sticks and leaves. Very turbid river waters are usually allowed to stand in large sedimentation basins to reduce the cost of operating the filters. Supplies objectionable on account of their iron content are aerated and allowed to trickle over rocks, allowing the oxidation of the ferrous carbonate in solution and the ferric oxide can then be removed by filtration.

The distinctive feature of a mechanical filter is the use of a coagulant and the high rate of filtration. Aluminum sulphate is the coagulant most commonly used. The water with the coagulant is allowed to stand 3 or 4 hours in a sedimentation basin and is then passed rapidly through beds of sand or ground stone to remove the rest of the sediment. If the alkalinity of the water supply is too low to give a proper reaction with the coagulant, lime or soda ash is added. The permanent hardness of the water will be increased if an excess of lime is employed.

Purification by the application of chemicals kills organisms that may cause disease or give bad taste or odor. Copper sulphate and calcium hypochlorite, and ozone, are the common disinfectants. Purification in this manner must be done by the application of substances not poisonous to animals.

Use of Hypochlorites.—An exceedingly important method of water treatment is in the use of hypochlorites. This has become a widely accepted method for bacterial purification of city water supplies, especially of the Great Lake supplies. Since hypochlorites are active oxidizing agents they are used for destroying organic matter and coloring; for bleaching, and other industrial uses of water. An excellent presentation of the use of hypochlorites is given in the work of Albert H. Hooker,[1] "Chloride of Lime in Sanitation".

Sewage Purification.—The problem of disposing of the sewage of cities is an important one with respect to the health of the communities. The purification of water supplies for drinking purposes, and the purification of sewage, are everywhere closely related, for it is usually

[1] Chloride of Lime in Sanitation, A. H. Hooker, Jno. Wiley & Sons, 1913.

the case that only the sewage polluted water supplies require purification. In only a few cities of Wisconsin, (see reference below), is the sewage treated in some sort of a disposal plant before being emptied into the waterways of the locality. In most instances, where the public water supplies are obtained from lakes and rivers, the sewage is emptied into the source of the water supply, and in such instances the city using a lake supply, pollutes its own water supply, while the city using a river supply pollutes the supply of the cities located farther down the river.

The problem of sewage purification is outside the scope of this report. Occasion, however, is taken in this place to refer the reader to a bulletin by Davis and Bowles[1], recently printed by the state, which adequately describes the sewage purification systems in Wisconsin, and which should be in the hands of all those interested in the public health of our cities.

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[1]Sewage Purification with Special Reference to Wisconsin Conditions, Bull. Univ. of Wis., No. 331, 1909.

CHAPTER VII.

THE CHEMICAL QUALITY AND THE FACTORS AFFECTING THE MINERALIZATION OF UNDERGROUND WATER.

The water supplies of Wisconsin, both surface and underground, show a considerable range in composition, the extent of mineralization varying in different parts of the state. Since the mineral content of the surface waters of rivers and lakes is much less than that of the underground waters of the same locality and is determined by influences somewhat different from those affecting the rock waters, the surface waters are briefly described in a separate chapter. The present chapter therefore is mainly confined to a general discussion, or summary, of the chemical quality of the underground waters and the factors influencing the degree of mineralization. The chemical data upon which the general discussion is based is fully stated in the tables of mineral analyses of each county in Part II, pp. 223 to 639.

Information in regard to the analyses of both the underground and surface waters of the state is wholly the result of compilation from various sources. Some of the analyses quoted were made by chemists to determine the value of waters for public supplies for cities, and many were made by industrial chemists to determine the value of the waters for boiler use in railroad locomotives. A few of the analyses of spring waters and highly mineralized waters have been made for the purpose of showing the therapeutic value of these waters. Only a few have been made for purely research work. No analyses have been made in connection with the present investigation on the water supplies of the state.

The mineral analyses, originally stated in the usual hypothetical combinations in grains per gallon or parts per million, have been recomputed to the ionic form in parts per million, so far as possible, in order that they may be compared with other analyses. The expression of the results of water analyses in ionic form in parts per million is now quite generally adopted by sanitary and research chemists, and also by many technical chemists.

The Chemical Quality of Underground Waters.

The underground waters of the state show a very great range in mineral content. Some of the soft water springs in the northern part of the state are very low in mineral content, as illustrated by such springs as that near Cedar, Iron county, containing only 22 parts per million of mineral matter, the well known Chippewa spring at Chippewa Falls with content of only 36 parts per million, and the Tomahawk spring at Tomahawk with only 41 parts per million.

On the other hand some very highly mineralized waters have been encountered in a few wells and mining explorations in various parts of the state. The highest mineralized water in the state, so far as known, was reached at a depth of about 2,075 feet below the surface in the Florence Iron mine at Florence in exploring for iron ore in the Pre-Cambrian formations. This water contained 18,799 parts per million of dissolved solids, and 5,122 parts per million of organic and volatile maater. See page 329. In exploring for copper ore near Osceola, a salt water was encountered at a depth of only 90 feet containing 16,995 parts per million of mineral matter. Salt waters containing over 10,000 parts per million of dissolved solids have been encountered in only two other places in the tate; at Sheboygan, Sheboygan county, and at Palmyra in Jefferson county.

There are but few localities, only 18, in the state, however where underground waters have been found that contain over 1,000 parts per million of dissolved solids. The relatively rare occurrence of these highly mineralized waters as well as their geographic distribution and geological source appear to indicate that they are exceptional rather than usual or common, and hence are considered as exceptional waters in the following discussion. Among the analyses of underground waters there are about 100 analyses of spring waters. As there is very slight difference in the mineral content of spring waters and of well waters of the same. locality, the spring waters are included with other waters from underground sources.

Leaving out of consideration the highly mineralized exceptional waters, the average mineral content of about 600 waters from springs and from wells in the surface deposits and in the indurated rock, which range in mineral content from 22 to 1,000 parts per million, is about 327 parts per million.

The degree of mineralization of the spring and well waters apparently depends, not so much upon the character of the geological formations as determined by the chemical composition, as uoon the general

depth and thickness of the water-bearing strata in which is contained the body of underground water. The relative simplicity of the geology of Wisconsin in its relation to the mineral quality of the underground water supplies, gives opportunity to divide the state into areas or districts characterized by waters of approximately equal degree of hardness and mineral content, the boundaries of such areas being determined mainly, but not strictly, by the water-bearing geological formations, as these increase in number and thickness in passing toward the outer boundaries of the state.

To facilitate the study of the chemical quality of the underground waters, therefore, it is convenient to describe them first with respect to their areal distribution or by districts, and second with respect to their geologic horizons.

Chemical Composition of the Underground Waters by Districts.

The underground waters of Wisconsin with respect to their general mineral quality and hardness can be divided conveniently into four areas or districts as follows:

District A. Area of soft water.[1]

District B. Area of medium hard water.

District C. Area of hard and very hard water.

District D. Area of very hard water.

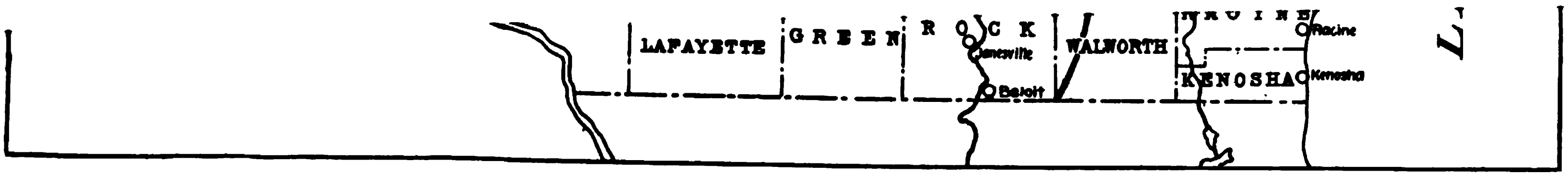
These districts are shown on the accompanying sketch map, Plate IV. It should be understood, of course, that the boundary lines between the various districts are somewhat arbitrarily drawn, as there is only a gradual and not an abrupt change in the mineral content in passing from one district to the other. Within each distict, however, the degree of mineralization of the underground water is approximately the same. Such a map may conveniently be referred to, in a general way, as a "water-composition map", or, a "*hydrosystatic*[2] *map*".

District A. Area of Soft Water.

The area of soft waters, that is, with waters having a total hardness averaging below 100 parts per million, is mainly confined to the north central part of the state, as shown on the accompanying sketch map. (Plate IV). This area is underlain very largely by crystalline rock of the Pre-Cambrian formations and of (See geological map) relatively

[1] For the definition of soft and hard waters, see page 146.

[2] *Hydrosystatic*, from Greek, *hydra*, water + *systasis*, composition.



The figures refer to total mineral content, parts per million, of the underground water of wells in the surface formation and in the underlying rock.

thin deposits of the Upper Cambrian (Potsdam) sandstone in the southern and western portions. The surface deposits consist mainly of glacial drift of crystalline debris on the uplands, and of alluvial deposits largely of quartz sand and granitic gravel, in the valleys.

The general character of the water in this area by counties is shown in the following table:

TABLE 22. *Average mineral content of underground water in the surface deposits and in the rock, by counties, in District A.*

Parts per million.

County.	Wells in the surface deposits, alluvial and glacial formations.									Wells in indurated rock, sandstone and granite.									
	Number of analyses.	Silica (Si O_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids.	Number of analyses.	Silica Si O_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids.	Mean total.
Adams	2	9	13	6	0.5	38	4	2	69	2	8	36	10	8	85	3	3	154	112
Clark	3	....	32	9	15	67	29	....	152	0	....	....	....	....	....	....	....	....	152
Chippewa	1	18	10	5	4	28	4	3	75	2	16	7	3	5	15	2	1	55	62
Eau Claire	4	17	16	6	9	29	21	9	118	0	....	....	....	....	....	....	....	....	118
Forest	1	21	23	5	9	35	31	13	140	0	....	....	....	....	....	....	....	....	155
Jackson	1	8	7	3	....	16	9	1	47	0	....	....	....	....	....	....	....	....	47
Juneau	6	5	18	6	9	24	42	5	110	0	....	....	....	....	....	....	....	....	110
Lincoln	10	4	17	6	8	44	5	4	92	0	....	....	....	....	....	....	....	....	92
Langlade	4	14	24	11	9	60	9	13	140	0	....	....	....	....	....	....	....	....	167
Marathon	10	9	18	5	9	42	15	3	101	0	....	....	....	....	....	....	....	....	101
Monroe	8	5	19	6	8	29	29	8	104	1	11	13	5	2	23	17	4	107	104
Oneida	4	11	19	7	7	42	16	8	103	0	....	....	....	....	....	....	....	....	103
Portage	3	11	39	19	3	93	25	4	197	4	....	31	18	7	46	61	3	174	184
Vilas	3	8	9	2	3	14	10	3	51	0	....	....	....	....	....	....	....	....	51
Washburn	1	16	24	7	1	43	1	3	109	0	....	....	....	....	....	....	....	....	109
Wood	8	....	42	13	13	80	50	9	219	0	....	....	....	....	....	....	....	....	219
Mean	69	8	22	7	8	45	22	5	121	9	12	25	11	6	44	30	3	135	122
Average of 78 analyses for the district										....	8	22	8	8	45	23	5	122	....

The analyses shown in the above table are mainly of shallow well-waters in surface deposits, a few analyses are of springs, and 9 are of waters from wells in the sandstone and in the granitic rock. The wells in the surface deposits range in depth from 10 feet to over 217 feet, while the deepest well in the sandstone reaches only 320 feet. For depths of the various wells, see the tables of mineral analyses under the county descriptions. Most of the wells in this district are less than 50 feet deep, and relatively few are over 100 feet deep. In general the depth of the underground water over the district will probably average between 100 and 200 feet, as measured by the average thickness of the

water bearing formations which overlie the impervious Pre-Cambrian Crystalline formations.

The mineral content of the underground waters in this district which comprises an area of about 20,000 square miles or 36 per cent of the state, so far as available analyses indicate, ranges from 36 parts per million in the Chippewa spring water to 278 parts per million in the water of the railroad well at Junction City in Portage county. The mean of 78 analyses shows an average content of 122 parts per million of mineral mater, which would be "low" in the classification in respect to mineral content. The average water of the district according to the classification in respect to hardness adopted in this report is "soft" the average hardness being between 85 and 90 parts per million.

It should be understood, of course, that many of the underground waters within this district are hard waters as the above table of mineral analyses clearly indicates. Usually however, the underground waters are likely to be low (below 150) in mineral content, and soft (below 100 parts of calcium and magnesium carbonate and calcium sulphate) and therefore would fall within the classification of soft waters as defined. According to the analyses the amount of boiler-scale formed by these soft waters would usually be less than 1 pound in 1,000 gallons, below that of the water of Lake Michigan.

It is undoubtedly true that many of the waters whose analyses are considered, are contaminated or polluted to a variable extent, and hence are somewhat higher in mineral content than the naturally pure water of the locality. To whatever extent the underground waters are contaminated, therefore, they represent waters higher in mineral content than the pure waters of the district.

District B. Area of Medium Hard Waters.

An area of medium hard water, that is of water with a mean content between 100 and 200 parts per million of hardness, surrounds the area of soft waters in the north central part of the state. This area, except in the region adjacent to Lake Superior, is characterized by the outcrop of thick beds of the Upper Cambrian sandstone and the relatively thin beds of the Lower Magnesian limestone (Oneota and Shakopee formations), and to some extent the overlying beds of the St Peter sandstone and the Galena-Platteville (Trenton) limestone. Adjacent to Lake Superior the indurated rock in this district is mainly the Lake Superior red sandstone.

The surface deposits consist of glacial drift containing limestone debris on the uplands except in the western part within the driftless

area where loessial deposits are prevalent. In the valley bottoms and adjacent to Lake Superior alluvial and lacustrine deposits are common, the alluvial deposits being largely sand and gravel, and the lacustrine deposits being largely reddish and bluish calcareous clays.

The wells in the valleys are quite shallow, usually less than 100 feet deep, while those on the uplands are relatively much deeper often from 200 to 300 feet deep. In general the depth of the body of underground water in the district is probably between 400 and 600 feet.

The chemical character of the underground water in the surface deposits and underlying rock within this district is shown in the following table:

TABLE 23—*Average Mineral Content of Underground Waters in Surface Deposits and the Rock, by Counties, in District "B".*

(Parts per million).

County.	Wells in the Surface Deposits.									Wells in the Rock.									
	No. of analyses.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg)	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	No. of Analyses.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg)	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean total solids.
Ashland'	0	....	....	....	....	....	....	....	....	3	9	37	22	33	82	....	60	255	255
Barron	0	....	....	....	....	....	....	....	....	1	20	38	14	2	85	....	4	163	163
Burnett	1	16	36	14	9	82	11	13	184	0	....	....	....	....	....	....	....	....	184
Columbia	1	....	14	5	7	40	2	3	72	2	....	20	10	11	45	4	25	117	102
Dunn	5	4	18	4	6	38	14	1	91	2	....	48	26	8	131	12	8	244	134
Iron	2	15	29	14	1	77	....	2	142	0	....	....	....	....	....	....	....	....	142
Forest	2	13	32	12	6	80	7	7	162	0	....	....	....	....	....	....	....	....	162
Juneau	0	....	....	....	....	....	....	....	....	4	17	44	19	16	80	81	16	287	287
LaCrosse	16	4	54	27	17	131	39	12	295	5	9	61	23	10	131	130	8	283	293
Langlade	1	17	53	25	6	140	7	7	257	0	....	....	....	....	....	....	....	....	257
Marinette	8	5	61	24	9	144	12	10	268	0	....	....	....	....	....	....	....	....	268
Marquette	1	13	47	35	1	149	7	1	258	0	....	....	....	....	....	....	....	....	258
Monroe	3	10	18	9	3	43	11	8	100	7	10	36	16	7	81	24	8	185	159
Pepin	0	....	....	....	....	....	....	....	....	2	5	54	30	6	156	11	1	265	265
Pierce	0	....	....	....	....	....	....	....	....	1	34	80	10	....	69	124	....	336	336
Polk	0	....	....	....	....	....	....	....	....	4	5	51	19	10	122	13	9	235	235
Richland	2	3	37	16	26	104	16	22	224	0	....	....	....	....	....	....	....	....	224
St. Croix	1	17	17	8	5	58	1	1	112	4	12	44	17	9	116	10	7	217	196
Sauk	2	9	58	32	8	168	11	4	292	6	12	34	16	3	91	2	3	162	194
Shawano	1	10	45	23	6	117	21	10	235	0	....	....	....	....	....	....	....	....	235
Trempealeau	0	....	....	....	....	....	....	....	....	3	7	41	22	9	121	14	5	228	228
Vernon	0	....	....	....	....	....	....	....	....	2	....	45	24	3	111	12	9	216	216
Waushara	4	16	43	19	4	109	2	8	208	0	....	....	....	....	....	....	....	....	208
Mean	51	7	42	20	10	109	19	8	224	46	9	43	14	10	102	22	11	216	220
	Average of 97 analyses for the district									....	8	43	17	10	106	20	10	220	

This district comprises an area of about 18,300 square miles, or about 33.6 per cent of the state. While the maximum range in mineral content is between 45 parts per million and 430 parts per million in well

waters, the usual range in mineral content is between 150 parts per million and 275 parts per million. The mean of 51 analyses of water from surface wells is 224 parts per million and the mean of 46 analyses of water from wells bottomed in rock is 216 parts per million. Some of the springs within the district contain as low as 22 and 33 parts per million. The average of all the analyses of underground waters in the district is 220 parts per million.

Calcium and magnesium are the principal basic constituents and only rarely are sodium and potassium more important than magnesium. Nearly all are carbonate waters and only very rarely is sulphate more important than carbonate.

The average hardness of the water of District "B" as measured by the calcium and magnesium carbonates and calcium sulphate is about 170 to 180 parts per million, and is therefore "medium hard" as defined in this report. See page 146. The average amount of encrusting solids in the groundwaters of the district is less than 2 pounds in 1,000 gallons, the usual range being between one pound and three pounds in 1,000 gallons.

District C. Area of Hard and Very Hard Waters.

An area with ground-waters having mineral content, appreciably higher than that in District B, lies to the east and south of the latter district. In this district there is a mean mineral content of the ground-waters of 335 parts per million and of about 308 parts per million of those constituents causing hardness.

This district comprises an area of about 9,900 square miles, about 18 per cent of the state, and lies along the Fox river valley in the eastern part of the state and south of the Wisconsin river below Portage in the southwestern part. This district is approximately co-extensive with the general outcrop area of the Galena-Platteville (Trenton) limestone. The eastern boundary of the district lies some distance west of the border of the Niagara limestone. The western boundary is a line approximating the western border of the relatively continuous outcrop of the Trenton. The indurated rock immediately underlying the surface deposits therefore, is very largely dolomitic limestone and only to a small extent sandstone.

The surface deposits in the glaciated portion of the district consist largely of limestone debris. In the valley bottoms of both glaciated and driftless areas the surface deposits are largely of alluvial origin and consist mainly of sand and gravel. Calcareous clays of lacustrine origin are common in the Fox river valley.

The wells in the valleys are usually less than 50 or 100 feet deep, while those on the uplands are often 200 to 300 feet deep. The approximate average depth of the body of underground water in the district, overlying the impervious Pre-Cambrian, is between 800 and 1,200 feet.

The mineral content of the underground water in surface deposits and in the rock in the district, by counties, is shown in the following table:

TABLE 24.—*Average mineral content of underground waters in the surface deposits and in the rock, by counties, in District C.*

Parts per million.

County.	Wells in the surface deposits.									Wells in the indurated rock.									
	Number of analyses.	Silica ($Si O_2$).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na + K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.	Number of analyses.	Silica ($Si O_2$).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na + K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.	Mean total solids.
Columbia	2	....	83	40	15	180	86	20	419	12	....	66	37	7	177	26	5	322	336
Crawford	1	1	44	14	17	84	52	8	223	3	2	51	26	24	150	18	15	287	271
Dane	6	6	64	37	9	175	38	6	335	12	8	68	38	15	170	54	17	374	361
Dodge	1	22	76	43	7	216	7	11	388	4	11	72	42	4	202	19	4	363	368
Green	6	6	75	33	13	182	28	9	351	7	4	70	34	14	166	18	18	331	341
Green Lake	4	16	63	39	8	152	76	4	362	1	24	59	32	2	158	18	1	308	351
Grant	4	10	53	21	7	125	11	5	245	12	7	67	40	9	184	43	10	376	343
Iowa	3	5	56	28	17	151	18	13	289	11	7	73	48	11	178	63	17	396	337
Jefferson	10	15	67	32	7	177	12	4	321	17	7	68	33	11	181	20	6	336	330
Lafayette	4	9	72	43	12	216	5	12	374	3	9	64	40	6	183	21	8	389	350
Marinette	1	20	38	9	6	72	10	9	166	0	....	....	....	....	....	....	....	....	166
Oconto	2	12	50	20	7	128	7	2	231	2	7	35	18	26	68	67	29	250	241
Outagamie	3	16	70	41	3	188	33	5	360	0	....	....	....	....	....	....	....	....	360
Rock	14	7	69	35	12	167	44	7	342	10	6	59	34	10	169	16	7	301	325
Shawano	0	....	....	....	....	....	....	....	....	1	19	51	31	14	154	9	14	296	296
Waupaca	4	18	68	35	5	177	30	7	343	0	....	....	....	....	....	....	....	....	343
Mean	65	10	66	34	10	168	31	7	330	95	6	66	36	11	174	33	11	339	....
Average of 160 analyses for the district									....	160	8	66	35	11	172	32	9	335	335

While the mineral content in the various individual counties of the district ranges between 166 and 477 parts per million, the mean mineral content of the entire district as shown by 65 analysis of water from springs and wells in surface deposits is 330 parts per million, and the mean mineral content as shown by 95 analyses of waters from wells in the rock is 339 parts per million.

While the underground waters in the district show a considerable range in mineral content a large majority of the waters analyzed

closely approximate the average mean analyses, which is about 335 parts per million of total dissolved solids, and about 308 parts per million of solids constituting hardness. In the classification adopted in respect to hardness, waters containing 200 to 300 parts per million of calcium and magnesium carbonate and calcium sulphate are hard waters, and waters above 300 parts per million of these constituents are very hard waters, hence, the waters of this district, according to this arbitrary classification, consist of hard and very hard waters in about equal proportions.

The mineral analyses show a mean content of about 3 pounds of incrusting solids in 1,000 gallons, the incrusting solids usually ranging between 2 and 4 pounds in 1,000 gallons.

District D. Area of Very Hard Water.

The area with underground waters having the highest mineral content in the state, lies in the eastern part of the state adjacent to Lake Michigan. In this district the mean content of dissolved solids in the underground water supplies is about 435 parts per million. The increase in the content of mineral matter in this district as compared with district C, is not very pronounced, but is sufficient to be characteristic for the area.

This district, as outlined on the sketch map, Pl. V, comprises an area of about 6,250 square miles or about 11.5 per cent of the state. It occupies a belt along Lake Michigan, from Door county on the north, to Kenosha county on the south, and geologically includes the area occupied by the Niagara limestone with a strip of the underlying formations on the west. The surface formations are mainly glacial drift containing much limestone debris, and the red calcareous clays of lacustrine origin.

The wells in the valleys are usually shallow, from 50 to 100 feet deep, while those on the uplands are quite deep, being usually from 100 to 300 feet deep. The depth of the body of underground water in the district in the water-bearing formations, overlying the impervious Pre-Cambrian granitic rock is approximately 1,600 to 2,000 feet deep.

The chemical composition of the underground waters in the surface deposits and in the rock, by counties, in the district, is shown in the following table:

TABLE 25.—*Average mineral content of underground waters in the surface deposits and the rock, by counties, in District D.*

Parts per million.

County.	Wells in the surface deposits.									Wells in the rock.									
	Number of analyses.	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total dissolved solids.	Number of analyses.	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4)	(Cl)	Total dissolved solids.	Mean total solids.
Calumet	3	14.	58.7	38.0	18.4	207.0	15.4	10.4	361.	3	19.0	57.3	38.4	19.6	156.8	80.3	22.0	339	350
Brown.........	7	11.	53.1	39.4	28.1	167.5	34.0	24.	367.	5	15.0	78.3	38.8	31.9	157.4	74.3	16.2	419.	389
Dodge.........	18	16.3	87.4	47.3	11.5	191.5	85.8	15.7	454.	7	14.2	75.5	36.4	22.6	176.9	74.1	10.3	409	438
Fond du Lac..	15	15.1	98.9	45.8	25.4	196.6	122.9	33.2	528	10	11.3	75.7	31.6	48.7	154.6	89.7	54.4	471	505
Kenosha.......	5	15.8	29.2	20.3	62.2	134.5	59.7	5.0	322	4	11.0	79.0	19.5	64.8	171.6	114.1	6.3	467.	387
Manitowoc....	2	10.9	46.6	23.8	12.1	124.1	14.	16.9	250.	2	....	64.8	42.7	11.9	160.8	78.6	9.6	379.	315
Milwaukee....	17	14.7	76.1	37.5	26.9	170.5	107.3	14.1	447.	29	11.	96.3	31.6	29.2	118.6	221.2	9.3	525	491
Outagamie....	2	15.0	50.6	27.2	18.7	141.5	47.8	6.2	308.	3	6.4	158.6	22.3	17.7	158.9	253	9	629	501
Ozaukee	4	13	74	33	11	179	34	7	358	2	8.	73	40	14	184.	55	10	383	366
Racine	4	....	67	34	36	138	148	6	435	21	....	96	23	41	137	174	10	489	481
Sheboygan....	6	....	83.8	41.	21	201	56	23	431	7	....	79	39	21	176	77	26	420	425
Walworth.....	14	9	78	39	11	194	28	7.	370	7	8	68	36	15	201	7	8	346	366
Washington ..	9	....	77	41	11	183	73	13	399	9	3	103	43	28	211	74	13	477	438
Waukesha	41	14	73	37	19	190	45	13	391	4	13	69	35	10	155	107	....	389	390
Winnebago....	7	....	64	41	18	198	47	8	385	0	....	....	....	....	....	....	....	....	385
Mean........	149	12	75	39	21	184	66	14	408	113	11	88	32	30	157	134	15	466	435
Average of 262 analyses for the District...........										....	11	81	36	25	172	92	15	43 5	....

While the maximum range in mineral content in the water in the several counties is from 250 parts per million to 964 parts per million, the usual range is between 300 and 550 parts per million. Including the 26 analyses of spring waters at Waukesha and also some other spring waters, the mean mineral content of 149 analyses of waters from surface deposits is 408 parts per million, and the mean mineral content of 113 analyses of water from wells in the rock is 467 parts per million, the average of the total of 262 analyses being 435 parts per million.

The numerous mineral springs at Waukesha appear to be appreciably lower in mineral content than the usual groundwaters of this district, the 29 analyses of these spring waters showing a mean content of 373 parts per million of mineral matter. The mineral waters of the Waukesha springs are classed on the market, generally, as light table waters. If the large number of analyses of these spring waters be excluded in calculating the general average character and mean mineral content of waters for the surface deposits, the average mineral content in the surface deposit wells would be 420 parts per million.

As in the other districts, calcium is very generally the most important basic constituent. However, sodium and potassium are relatively much more important in this district than in the other districts and is usually more important than magnesium. Carbonate is very generally the predominating acid radical, though sulphate is more important in this district than in the other districts. In many of the waters, the sulphates exceed the carbonates. The underground waters of this district, therefore, are generally appreciably higher in sodium and potassium and in sulphates than in District C.

An area in Kenosha county contains ground-water in the surface deposits and the Niagara limestone in which sodium and potassium carbonate is relatively high and calcium and magnesium carbonate relatively low. These waters are soft waters of a somewhat different type from those in District A, of the north central part of the state. One of the waters analyzed from Kenosha County, see page 183 is apparently a typical "alkali" water.

With the exception of the soft sodium carbonate waters in Kenosha county, most of the waters analyzed in this district contain more than 300 parts per million of those mineral constituents, calcium and magnesium carbonate and calcium sulphate causing hardness in waters, and hence, according to the classification adopted in this report, the waters of this district would usually be very hard waters. The average hardness of the 262 analyses is about 350 parts per million.

The hardness of the prevailing ground-waters of this district, however, as already stated, is about the same as that of much of the waters in the so-called soft water districts in the adjoining states south of Wisconsin.

The analyses show a mean content of about 4 pounds of incrusting solids in 1,000 gallons of water, the usual range being between 3 and 5 pounds in 1,000 gallons, as compared with a little over one pound in Lake Michigan water.

Exceptional Waters. Highly Mineralized Waters

In various parts of the state, waters of very high mineral content have been encountered. Since these are of relatively rare occurrence, they may be classed as exceptional rather than normal, though they are of course, of perfectly normal development in the rock strata in which they occur.

In some parts of the state, an underground water with mineral content of 800 to 1,000 parts per million would be exceptional, while in other parts, water with only 500 or 600 parts per million would be

exceptional. With respect to underground waters of the entire state, it appears to be a fair assumption to consider waters containing above 1,000 parts per million of dissolved solids exceptional or unusual. Those below 1,000 parts per million in mineral content are considered as of fairly common occurrence and, therefore, have been included in arriving at general conclusions in regard to the average prevailing chemical character of the waters likely to be encountered in the various districts above described.

Distribution of Highly Mineralized Waters

There appear to be only 18 places in the state in which waters above 1,000 parts per million in mineral content are definitely known to have been encountered. Most of these places (See sketch map Plate V) are distributed about the border of the state, and many of the localities occur along the shore of Lake Michigan. No highly mineralized water is known to occur in the area of soft water in the north central part of the state. However, highly mineralized waters are likely to be found in the future in all parts of the state, although their relative abundance and distribution are very likely fairly well indicated by our present knowledge of their occurrence.

The location, geologic source and total mineral content of the highly mineralized waters are shown in the following table:

TABLE 26. *Showing locality and source of highly mineralized waters and salt waters.*

County.	Locality.	Depth of well in feet.	Geological formation.	Total mineral content.
Ashland	Ashland	3,095	Lake Superior sandstone (Keweenawan)	945*a*
Brown	Askeaton	1,000	St. Peter and Upper Cambrian sandstone	1,886
Crawford	Prairie du Chien	960	Upper Cambrian (Potsdam) sandstone	2,338
Florence	Florence	2,075	Pre-Cambrian carbonaceous schist	18,799 dis. solids. 5.122 volatile
Jefferson	Palmyra	750	Upper Cambrian sandstone	11,594
Jefferson	Waterloo		Probably Upper Cambrian sandstone	2,372
Manitowoc	Manitowoc	110	Niagara limestone	2,544
Manitowoc	Manitowoc	150	Niagara limestone	3,244
Marinette	Marinette	716	Upper Cambrian sandstone	1,218
Milwaukee	Milwaukee	Spring?	Glacial drift or Niagara limestone	4,643
Milwaukee	Milwaukee	160	Niagara limestone	1,476
Milwaukee	Milwaukee	1,048	St. Peter and Upper Cambrian sandstone	1,419
Milwaukee	North Milwaukee	1,600	St. Peter and Upper Cambrian sandstone	1,266
Outagamie	Town of Buchanan	8	Galena limestone or Cincinnati shale	2,132
Outagamie	Kaukauna	798	Upper Cambrian sandstone	1,350
Ozaukee	Mequon	1,420	St. Peter and Upper Cambrian sandstones	2,552
Polk	Near Osceola	50	Upper Cambrian sandstone	1,457
Polk	Near Osceola	40 to 90	Upper Cambrian sandstone at contact with Keweenawan trap	16,995
Sheboygan	Oostburg	550	Probably Niagara limestone	1,180
Sheboygan	Random Lake	1,038	St. Peter and Lower Magnesian formations	1,246
Sheboygan	Sheboygan Falls	1,200	St. Peter and Lower Magnesian formations	7,382
Sheboygan	Sheboygan	1,476	St. Peter and Lower Magnesian formations	10,053
Sheboygan	Sheboygan	1,402	St. Peter and Lower Magnesian formations	10,441
Washington	Hartford	14	Surface formation	1,313

a Average of 3 analyses of samples taken at 1435, 2000 and 2800 feet.

Besides the occurrence of highly mineralized waters at Ashland, salty water is also reported in some of the deep wells at Superior.

The depth of wells in which highly mineralized waters have been encountered, range from only a few feet up to over 3,000 feet. The depths of wells, as shown in the table, are total depths and the exact depth at which the salt water was encountered is very generally unknown. In a few instances, however, the depth of strata in which salt water is encountered is known and is fully described in the description of the water supplies of the counties in which they occur.

The geological source of these highly mineralized waters range from the surface deposits to the Pre-Cambrian. Most of them, however, are obtained from deep wells that penetrate a considerable thickness of water-bearing strata, for other factors being equal, the more water-bearing strata tapped the more likely is a highly mineralized water to be en-

countered. The deeper the sea of underground water, the higher is the degree of mineralization of the water, as described more fully later.

Of the eighteen highly mineralized or salt waters twelve are sulphate waters, five are chloride waters and one, in Milwaukee, is a carbonate water. "Calcium" waters and "sodium" (sodium and potassium) waters occur in about equal proportion among these highly mineralized waters. The salt water near Osceola in Polk county belongs to the relatively rare class of calcium chloride waters. In only one, the Waterloo well, are nitrates a prominent constituent.

Relation of the Chemical Quality of the Underground Water to the Geological Formations

In the discussion of the quality of the underground waters in various districts into which the state has been divided no attempt has been made to describe the quality of the water in respect to the geologic source except as such districts are determined by the outcrop of certain geological strata. In many instances, it is not possible to determine definitely the stratigraphic source of the water. Especially is this true where the wells extend to a considerable depth and penetrate several water bearing horizons. However, the geological structure of Wisconsin, with the successive strata lying over each other in regular order from the central to the outer portions of the state, like an imbricated pattern, lends itself very effectually to the satisfactory study of the quality of the water supplies in relation to the geological source. In a very large proportion of the wells, it is believed the geological source of the water can be determined with sufficient accuracy for the purpose of comparing the chemical quality of the water in the various important geologic strata.

Quality of Water in Pre-Cambrian Crystalline Rocks

Only a few analyses of water from wells in the Pre-Cambrian crystalline rocks have been made, and since the Pre-Cambrian is relatively impervious, the waters in such wells have very generally seeped down from the immediately overlying formation of drift or thin sandstone and thus have the general quality of the water in the surface deposits of the locality.

No analyses of underground water from granite rock are available but judging from the analyses of water from glacial drift made up largely of granitic debris, the waters are quite likely to be uniformly of very low mineral content, and usually soft water. The chemical com-

position and slight insolubility of granite is also such as to indicate that waters of only very low mineral content characterize this class of rock. The groundwater in dark colored basic igneous rocks which are relatively low in silica and high in calcium, magnesia and iron, such as greenstone and the Keweenawan trap, are likely to be more mineralized than the waters in the light colored silicious granites and gneisses. The water in the Keweenawan trap rocks appear to be mineralized to a considerable degree in many of the deep copper mines in the region of upper Michigan.[1] It seems very probable, therefore, that somewhat similar highly mineralized water may occur in the Keweenawan trap in Wisconsin. Such highly mineralized waters, however, are not so likely to be encountered in ordinary shallow wells in the trap, as in wells of considerable depth.

The ground waters available for water supplies in the Pre-Cambrian rocks are very probably mineralized only to a slight extent.

Waters in the quartzite are likely to be low in mineral content, and the same is also probably true of waters in the slates and iron-bearing rock. Two analyses of water from the Pre-Cambrian iron formation rock in the Baraboo district (See page 558) contain only 134 and 147 parts per million of dissolved solids. Slate formations, however, that contain carbonaceous matter, and iron pyrites, (iron sulphides), are likely to be highly mineralized, as shown by the salt water from the Florence iron mine. (See page 329).

While the underground waters from shallow wells in the Pre-Cambrian formations within the outcrop area of the Pre-Cambrian are likely to be low in mineral content in granite, quartzite, slate, and iron formations, highly mineralized waters may be encountered from deep-lying sources and especially in certain phases of Pre-Cambrian graphitic and pyritiferous slates and in the Keweenawan trap.

The depth of the sea of underground water in a water-bearing formation, as a factor affecting the mineral content, is more fully referred to in the following pages and the application of this principle to the mineralization of the underground waters in the Pre-Cambrian is briefly referred to on page 197–9.

Quality of Water in the Lake Superior Red Sandstone

Adjacent to Lake Superior some of the deep wells in the great thicknes of red sandstone and shale appear to contain water of relatively high mineral content and often of distinctly salty taste. While only one an-

[1] A. C. Lane, "Mine Waters", Lake Sup. Min. Inst., Vol. XIII, 1908, pp. 63–152.

alysis of highly mineralized water from this formation is at hand (See page 233) waters of salty taste have been reported to occur in other deep wells in this formation at Ashland and at Superior, and judging from the character of the formation it appears to be likely that highly mineralized waters are a characteristic feature. Highly mineralized or salt waters, however, are not so likely to be found in shallow wells as in deep wells in this formation for in the shallow wells the slightly mineralized surface waters are likely to predominate. In a general way also, the deeper the well, the greater the chance for penetrating salt water horizons.

The very great thickness of the red sandstone in the Lake Superior basin (estimated to be 22,000 feet) and in consequence the great depth to which the underground waters extend, undoubtedly exerts a potent influence on the high degree of mineralization of the underground water and is referred to again on page 198.

Quality of Water in the Upper Cambrian and St. Peter Sandstone

The Upper Cambrian (Potsdam) and the St. Peter sandstone formations, as well as the interposed Lower Magnesian formation, may be conveniently discussed together, since there is generally no essential difference in the quality of their waters. Furthermore, it is generally impossible to separate these formations from one another in many of the deep wells, on account of incomplete data, as well as the variable thickness of the strata within the St. Peter and Lower Magnesian horizons. The fact that the quality of the waters is about the same, whether from the St. Peter sandstone or from the Lower Magnesian strata has also been noted[1] in the outcrop area of these formations in northeastern Iowa.

There is a gradual increase in the mineral content of the water in the sandstone water-bearing horizons as their depth below the land surface increases, and hence it is of interest to discuss separately the quality of the water in the sandstone horizons with reference to their position under the overlying formations of Galena-Platteville (Trenton) limestone, and under the Niagara limestone, as well as within the general outcrop area of the Potsdam and Lower Magnesian formations.

[1]"Underground Water Resources of Iowa". U. S. Geol. Sur. W. S. P. 293, p. 102.

Quality of the Sandstone Water in the Outcrop Area of the Upper Cambrian and Lower Magnesian Formations

Within this district, mainly District B, above described, the wells in this group may range in depth between a few feet up to 600 or 1,000 feet. However, in those wells, waters of which have been analyzed, only a few are more than 500 feet deep. These wells are usually in cities located in the valleys, and hence the waters probably represent a fair average of the water that has seeped through the entire thickness of strata extending over the surrounding region.

The average mineralization of the waters in the sandstone within the general outcrop area of the sandstone from 42 wells in Adams, Barron, Chippewa, Columbia, Dunn, Juneau, La Crosse, Monroe, Pepin, Polk, St. Croix, Sauk, Trempealeau and Vernon counties is shown in the following table:

TABLE 27. *Average mineral content of the water in the Upper Cambrian (Potsdam) sandstone in the general outcrop area of the Potsdam and Lower Magnesian.*

(Parts per million.)

County.	Number of analysis averaged.	Silica (SiO^2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO^3).	Sulphate radicle (SO^4).	Chlorine Cl.	Total dissolved solids.
Adams	2	8	36	10	8	85	3	3	154
Barron	1	20	33	14	2	85	......	4	163
Chippewa	1	26	9	5	1	24	2	1	75
Columbia	2	......	20	10	11	45	4	25	117
Dunn	2	......	48	26	8	131	12	8	244
Juneau	4	17	44	19	16	80	81	16	287
La Crosse	5	9	61	28	10	131	30	8	283
Monroe	8	10	33	15	6	74	23	8	175
Pepin	2	5	54	30	8	156	11	1	265
Polk	2	8	43	14	......	89	16	......	170
St. Croix	4	12	44	17	9	116	10	7	217
Sauk	4	10	37	17	3	98	1	3	173
Trempealeau	3	7	41	22	9	121	14	5	228
Vernon	2	......	45	24	3	111	12	9	216
Mean	42	11	41	18	8	98	20	8	209

Within this district of the outcrop area of this group of water-bearing strata, the average total mineral content of 42 analyses of underground water is 205 parts per million of dissolved solids, the range in mineral content usually being between 100 and 300 parts per million.

Quality of the Water in the Sandstone Under the Outcrop Area of the Galena-Platteville Limestone

This district corresponds closely to District C. (See Plate V), and wells range in depth from about 200 or 300 feet, in the case of those which penetrate through the Galena-Platteville and enter only a short distance into the immediately underlying St. Peter sandstone, to those 1,000 to 1,700 feet deep that reach mainly or entirely through the Potsdam sandstone and all overlying formations. While there is undoubtedly a mixture of the water from the Galena and Platteville limestones with that obtained from the underlying sandstone in many of the wells that penetrate both groups of strata, yet in most instances the source of the water under consideration appears to be mainly or entirely from the sandstone. Especially is this the case in those wells that obtain strong artesian flows from the sandstone underlying the Galena-Platteville in the eastern part of the state.

The average mineral content of the sandstone water mainly from the Potsdam under the Galena-Platteville limestone, from 98 wells in Brown, Columbia, Crawford, Dane, Dodge, Fond du Lac, Grant, Green, Green Lake, Jefferson, La Fayette, Oconto, Outagamie, Rock, and Walworth is shown in the following table:

TABLE 28—*Average mineral content of water in the Upper Cambrian (Potsdam) and St. Peter sandstones under the Galena-Platteville limestone.*

(Parts per million.)

County.	Number of analyses averaged.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (Co_3).	Sulphate radicle (So_4).	Chlorine (Cl).	Total dissolved solids.
Brown	3	19	48	31	38	141	63	16	351
Columbia	12	......	66	37	7	177	21	5	336
Crawford	3	2	51	26	24	150	18	15	287
Dane	8	10	64	37	11	182	30	5	333
Dodge	7	12	79	41	19	186	80	8	426
Fond du Lac	8	9	65	25	46	115	90	54	409
Green	4	5	61	39	10	177	22	15	338
Green Lake	1	24	59	32	2	158	18	1	308
Grant	7	6	62	37	7	172	22	10	318
Iowa	6	10	64	37	6	118	27	7	321
Jefferson	16	7	68	32	11	180	16	5	332
Lafayette	1	1	68	40	11	180	34	17	359
Oconto	2	7	35	18	26	63	67	29	250
Outagamie	3	6	158	22	17	158	253	9	629
Rock	10	6	59	34	10	169	16	7	301
Walworth	7	8	68	36	15	201	7	8	346
Mean	98	8	67	34	15	170	40	12	349

The mean total mineral content of 98 analyes of water from the sandstone group, within the general district of the Galena-Platteville limestone, from wells that penetrate through the overlying limestone and from wells obtaining their supply from the sandstone with the limestone on the higher levels of the adjacent land, is 349 parts per million. The increase in the average mineralization of the waters in the sandstone underlying the Galena-Platteville over that outside the outcrop of the latter, is about 41 per cent, sufficient to be worthy of consideration in connection with industrial use of the water. There is, of course, no sharp increase in mineralization of the water at the boundary of the Galena-Platteville outcrop, but it may be stated that, very generally, the waters in the underlying sandstone group are appreciably higher in mineralization than they are outside the district occupied by the Galena-Platteville formation. The cause of the increased mineralization is probably mainly due, as more fully described later, to the increased pressure on the underground water and higher temperature and other conditions developed in the sandstone in consequence of the greater depth of the sandstone strata.

Quality of the Water in the Sandstone under the Niagara Limestone in Eastern Wisconsin

This district corresponds closely to District D., above described, and wells that draw their supply from the sandstone group in this area may have a depth of 500 to 1,000 feet in wells that reach only a short distance into this group, to an approximate maximum depth of 2,000 to 2,200 feet, in wells that reach through the several formations overlying the entire thickness of the sandstone group. While there is undoubtedly a mixture of water obtained from the deep artesian wells, due to water flowing in from formations overlying the sandstone group, yet in most instances, the source of the water considered appears to be from the sandstone group in sufficient instances and in sufficient quantity to indicate the usually prevailing quality of the sandstone water. The water in the sandstone group in this district is very generally under strong pressure and for this reason forms a very large proportion of the artesian water flowing or pumped from the deep wells.

The average mineralization of the sandstone water in this district from 47 wells in Brown, Calumet, Kenosha, Milwaukee, Racine, Sheboygan and Waukesha counties is shown in the following table:

TABLE 29. *Average mineral content of water in the Upper Cambrian (Potsdam) and St. Peter sandstones under the Niagara and Galena-Platteville limestones.*

(Parts per million.)

County.	Number of analyses averaged.	Silica (SiO_2)	Calcium (Ca).	Magnesium. (Mg).	Sodium and potassium. (Na+K).	Carbonate radicle. (CO_3).	Sulphate radicle. (SO_4).	Chlorine Cl.	Total dissolved solids.
Brown	1	18	179	55	39	171	133	23	652
Calumet	2	19	58	28	18	138	30	28	329
Kenosha	3	12	104	25	36	164	149	8	500
Milwaukee	16	11	125	32	22	128	265	9	503
Racine	17	......	101	21	37	136	160	9	473
Sheboygan	4	......	102	44	23	196	121	32	511
Waukesha	4	13	69	35	10	155	107	7	389
Mean	47	12	107	29	28	143	181	12	509

The average total mineral content of the 47 analyses of water from wells 764 to 2,000 feet deep that reach the sandstone group under the outcrop of Niagara limestone is 509 parts per million, the range in mineral content, by counties, being between 329 and 652 parts per million. The increase (160 parts per million) or about 31 per cent in mineralization of the water in the sandstone under the Niagara limestone over that under the outcrop area of the Galena-Platteville, is about the same as the increase (144 parts per million) observed in the outcrop area of the Galena-Platteville over that in the outcrop area of the the sandstone. There is apparently no sharp increase at the boundary of the Niagara outcrop, but in a general way, there is a gradual increase in the mineral content of the water in this group in passing from the outcrop area of Galena-Platteville to that of the Niagara.

QUALITY OF THE WATER IN THE GALENA-PLATTEVILLE LIMESTONE

The Galena-Platteville limestone is an important source of water supply within the southwestern driftless part of the state where this formation is the predominating surface rock. In shallow wells throughout Grant, Iowa, La Fayette, and Green counties it affords an excellent and abundant supply.

Farther east, in Rock, Jefferson, Dodge, and Fond du Lac counties it is also an important source of supply but in these counties the sand and gravel beds in the glacial drift, overlying the Galena-Platteville, usually furnish an adequate supply for most purposes. Still farther east, in the counties adjacent to Lake Michigan, in the outcrop area of the Niagara limestone, the Galena-Platteville furnishes supplies only to

a relatively unimportant extent, as wells in that district, either draw their supplies from shallow wells in the drift and in the underlying Niagara limestone or from deep wells that reach through the Galena-Platteville into the underlying sandstones.

The average mineral content of the water in the Galena-Platteville in Dane, Dodge, Fond du Lac, Grant, Green, Iowa, La Fayette and Shawano counties is shown in the following table:

TABLE 30. *Average mineral content of water in the Galena-Platteville limestone.*
(Parts per million.)

County.	Number of analyses averaged.	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total dissolved solids.
Dane	2	10	72	38	25	175	30	43	397
Dodge	3	15	67	35	13	194	6	10	343
Fond du Lac	1	14	100	36	24	251	28	6	475
Grant	5	11	75	44	12	181	73	11	410
Green	2	......	107	33	27	188	20	33	411
Iowa	4	10	76	53	14	186	101	17	461
Lafayette	2	13	62	40	3	184	15	3	328
Shawano	1	19	51	31	15	154	10	14	296
Mean	20	12	75	41	15	186	47	16	400

The water in the Galena-Platteville limestone within the outcrop area of this formation is very generally "hard" or "very hard" as classified in this report, the mean total mineral content in 20 analyses being 400 parts per million, the usual range in total solids being between 300 and 500 parts per million. While there are exceptions, it appears to be the general rule that the Galena-Platteville water is somewhat higher in mineral content than the underlying sandstone water. The somewhat higher mineralization of the water in the Galena-Platteville as compared with that in the underlying sandstone is perhaps fairly well illustrated by the analyses of water in these horizons in Iowa county and in Grant county as shown in Table 31. On the other hand the average of two analyses of water in the Galena-Platteville in La Fayette county (See Table 31) show a slightly lower mineral content than a single analysis of water in the underlying St. Peter formation.

There is, therefore, very generally an appreciably higher mineral content in the Galena-Platteville water than in the water of the underlying sandstone within the general outcrop area of these formations as shown in table 31. The higher mineral content in the Galena-Platteville water appears to be fairly well illustrated in the table by the av-

erage mineralization of 400 parts per million as compared with 352 parts per million in the sandstone water.

TABLE 31. *Comparison of average mineral content of water in the Galena-Platteville limestone with that in the underlying Upper Cambrian and St. Peter sandstones.*

County.	Wells in the Galena-Platteville limestone.			Wells in the underlying sandstone.		
	Number of analyses averaged.	Average depth of wells.	Average mineral content.	Number of analyses averaged.	Average depth of wells.	Average mineral content.
Dane	2	170	397	8	685	333
Dodge	3	308	343	7	266	426
Grant	5	101	410	7	994	318
Green	2	25	411	4	1000	338
Iowa	4	172	461	6	208	321
La Fayette	2	66	328	1	300	359
Mean	18	146	400	33	600	352

No analyses are available of waters from deep wells in the Galena-Platteville formations underlying the Niagara limestone, but it is very probable that these waters are very generally higher in mineral content than the Galena-Platteville waters in shallow wells in the outcrop area of the latter.

QUALITY OF WATER IN THE CINCINNATI SHALE

The thick Cincinnati (Maquoketa) shale is practically negligible as a water-bearing horizon, but the impervious character of the formation forms an impenetrable floor for the Niagara and the drift waters above it, and it serves as confining strata for the underlying waters within the Galena-Platteville limestone and the sandstone group.

While no analyses are available of waters obtained from this shale, it is believed that the shale waters, while very meager, are relatively much higher in mineral content than waters in the associated formations. The several analyses of well water at Oakfield, Fond du Lac county (See page 343), where the shale is the bed rock formation, show a relatively high content of dissolved solids which may be due to the shale. However, as this formation yields practically no water, the quality is obviously unimportant.

Quality of Water in the Niagara Limestone

Throughout its area in eastern Wisconsin, the Niagara limestone is almost exclusively the source of water supply in shallow rock wells. This formation is usually from 200 to 300 feet thick and it transmits water very freely, not only through many small crevices but also through numerous large joints, cracks, and along bedding planes.

The water in the Niagara is usually very hard water though of moderate mineral content. In a few instances, however, highly mineralized waters have been encountered, and in some instances very soft waters though of moderate mineral content have been obtained. Only a few analyses of water wholly obtained from the Niagara are available but there are many analyses of waters from the overlying drift deposits made up largely of debris obtained from this formation, and such drift waters may be reasonably considered to closely reflect the general character of the immediately underlying Niagara waters.

The average mineral content of 35 analyses of waters from wells in the Niagara is shown in the following table:

TABLE 32. *Average mineral content of water in the Niagara limestone.*
(Parts per million.)

County.	Number of analyses averaged.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.
Calumet	1	......	55	45	22	195	31	9	357
Kenosha	1	9	3	1	149	195	9	2	369
Manitowoc	2	......	65	43	12	161	78	9	379
Milwaukee	13	......	68	33	38	115	184	10	450
Ozaukee	2	8	73	40	14	184	55	10	383
Racine	4	......	75	32	60	112	232	13	528
Sheboygan	3	12	49	32	19	150	18	19	298
Washington	9	3	103	43	28	211	74	13	477
Mean	35	6	74	36	36	154	124	12	440

The average mineral content of the Niagara water is 440 parts per million, the usual range in mineral content being between 300 and 600 parts per million. As the wells from which the waters were analyzed are necessarily cased through the overlying surface deposits and a few feet into the Niagara, the source may be considered as reasonably certain in the latter formation.

At Sheboygan, in Sheboygan county, and at Manitowoc, Manitowoc county, highly mineralized sulphate waters have been encountered in

the Niagara. However, these highly mineralized waters are believed to be of relatively unusual occurrences in this formation.

In Kenosha county, very soft sodium carbonate waters have been encountered in the Niagara and in the overlying surface deposits. It is a rather unique circumstance that the "softest" water in the state should be obtained from the Niagara limestone. This soft Niagara water, however, is not low but moderate in total mineral content. This water is apparently typical "alkali water". The mineral analyses of this soft Niagara water at Bassetts, Kenosha county, from a 224 foot well, also given with other analyses of the county table (page 400), is as follows:

Mineral Analyses of soft sodium carbonate water in Niagara Limestone, Bassetts, Kenosha County.

(Parts per million.)

Source.	Silica (SiO_2).	Calcium (Ca).	Magnesium. (Mg).	Sodium and potassium (Na& K)	Carbonate (CO_3).	Sulphate (SO_4).	Chlorine (Cl).	Total dissolved solids.
Niagara Limestone	8.9	3.	1.3	149.7	195.5	8.9	2.1	369

Soft sodium carbonate waters of this type appear to be characteristic over a considerable area of the Niagara in the locality about Bassetts, Bain, and Bristol in southern Kenosha county, the source being in the upper portion of the Niagara and in a gravel bed immediately overlying the Niagara (See page 400). Their occurrences suggests the possibility of other soft water areas within the Niagara district. However, these soft sodium waters, like the highly mineralized waters in the Niagara, may, under present knowledge, be considered as exceptional, the usual waters being very hard waters ranging between 250 and 500 parts of incrusting solids per million.

Quality of Water in the Surface Deposits

The mineralization of the underground water in the unconsolidated surface deposits, is generally very similar in character and degree to the mineralization of the water in the underlying rock. This fact has already been shown in the general discussion of the quality of the waters in the various districts. There is a close similarity in the mineral

quality of the water in the surface deposits and in the underlying rock for two principal reasons; first, the general similarity in chemical composition of the surface deposits, especially of the glacial drift, and of the underlying rock; and second, there is generally a very extensive intermingling and mixture of water and diffusion of dissolved salts throughout underground channels that extend up ito the surface deposits from the underlying rock.

The average mineralization of the underground water in the surface deposits, mainly the glacial drift and alluvial deposits, is shown in the following table:

TABLE 33. *Average mineral content of water in the surface deposits in the various districts of Wisconsin.*

(Parts per million.)

District.	Number of analyses averaged.	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total dissolved solids.
North central, District A	69	8	22	7	8	45	22	5	121
South central and western, District B	51	7	42	20	10	109	19	8	224
East central and south western, District C	65	10	66	34	10	168	31	7	330
Eastern, District D	149	12	75	39	21	184	66	14	408

The table shows a progressive increase in the mineral content in the water of the surface deposits in passing from the north central part of the state to the eastern part, adjacent to Lake Michigan. The mineralization of the water in the surface deposits is much the same as that in the underlying rock of the several districts.

However, while there is generally a close similarity in the mineral and chemical character of the surface deposits to that of the underlying rock, there are some exceptions to this general rule. Where there is a marked difference in the composition of the surface deposits and of the underlying rock, important differences may develop in the quality of the waters in the surface deposits and the rock in some localities.

It appears to be quite often the condition in Wisconsin, that the composition of the surface deposits may be of such a nature as to greatly modify or even to determine the general character of the rock waters in the region. In those portions of the state where glacial deposits consisting largely of limestone debris overlie the thin sandstone and Pre-Cambrian crystalline area, the hard waters derived from the limestone-

bearing drift may add appreciably to the average hardness of the water in the underlying rock.

Quality of Water in the Crystalline Drift

Those drift deposits of the state containing only the ground up rock debris, derived from the Pre-Cambrian crystalline rocks, very generally contain soft waters of low mineral content. The quality of water in the crystalline drift is fairly well illustrated by the table showing the average mineral analyses of the ground waters in District A, the north-central part of the state. While many of the analyses of ground water in this district are from wells in alluvial deposits, the latter are closely associated with the drift and the material of the alluvial deposits, such as gravel and sand, are very largely derived from the various crystalline rocks. The average mineral content of the water in the crystalline drift may be considered as about 121 parts per million as illustrated by the analyses of the water of the surface deposits in District A in the preceding table (Table 33).

Quality of Water in Limestone Drift

The drift deposits of the state containing an appreciable content of limestone rock, derived from the limestone formations of Wisconsin and the adjoining states, very generally contain hard waters or very hard waters of moderate mineral content. Where limestone drift overlies the crystalline area or overlies the sandstone formation, the ground water of the locality appears to be appreciably higher in mineral content than where such limestone drift is absent. Because of the work of the glaciers the district of hard waters, District B, enroaches considerably upon the general area of the Pre-Cambrian in northern Wisconsin.

The district of soft water, District A, would probably have been much larger if the ice sheets advancing from northeastern Wisconsin and upper Michigan had not transported limestone bearing drift into the eastern part of the crystalline area, into Forest, Langlade, Shawano, and Waupaca counties. To a certain extent, also, limestone bearing drift has been carried into northern Polk and into Burnett counties from northern Minnesota and Manitoba, thereby developing deposits containing a higher content of readily soluble mineral matter than would otherwise have obtained in that region.

The character and extent of mineralization of the water in the limestone drift is fairly well represented by the mineral analyses of the water in the surface deposits in the eastern limestone portion of the state,

as the southwestern limestone portion of the state is driftless. While a few analyses from the southwestern part of the state are included in table 33, they are not sufficiently different from those in the drift to affect the general averages. The average mineral content of water in the limestone drift is shown in the preceding table 33 as illustrated by the average mineralization of the water in the surface deposits of District C to be 330 and of District D 408 parts per million.

The table clearly shows an appreciable increase in mineralization of the limestone drift water in passing from the central portion of the state towards the eastern border. This increase, however, is probably not due to any change in the composition of the drift, for there is no appreciable change in character of the drift, but to the general increase in the mineralization of the underground waters throughout all the formations in the eastern part of the state. The increase in mineralization of the drift water in the eastern border of the state, District D, therefore, is considered to be due to the general mixture and intermixture of the water and the general diffusion of mineral salts in the water from deep seated and underlying sources, along vertical joint and fracture planes, that extend throughout the indurated rocks and under the drift.

Quality of Water in Alluvial Deposits

The alluvial deposits consist mainly of river deposited sands and gravels in the valleys, not only in the driftless area, but also to a very large extent in the glaciated parts of the state. In the glaciated parts of the state, the alluvial deposits are closely associated with the glacial drift and glacial outwash, and contain ground waters of similar mineral quality as the associated drift. In the driftless area, the alluvial sands and gravels form important deposits in the lowlands and in the valleys, and the material of the deposits consists largely of quartz sand derived from the adjacent sandstone formations.

While the alluvial sand contains water slightly less mineralized than that of the adjacent rock strata, there is apparently not a very noticeable difference in the various analyses of waters from these two sources in Wisconsin. This slight difference is very probably due to the fact that the alluvial waters in the valley deposits are very largely seepage waters from the adjacent rock uplands and, therefore, are very largely rock waters flowing underground down the valleys.

There is a considerable difference, however, in the degree of mineralization of the water in the alluvial sand of the broad valley bottom of the Wisconsin river, in Wood and Juneau and Monroe counties, and that in the alluvial sand in the narrow valleys farther south and west, in the

region of the high bluffs of sandstone, or of sandstone capped by limestone. In Monroe county the underground water in this alluvial sand, in the broad valleys about Tomah and Sparta, is much lower in mineral content than the water in the alluvial sand in the narrow valley of La Crosse river as shown in the following table:

TABLE 34. *Average mineral content of water in alluvial sand in Monroe and La Crosse counties.*

County.	Locality.	Number of analyses averaged.	Average total mineral content.
Monroe	Tomah and Sparta	11	103
La Crosse	La Crosse	16	295

While some of the analyses included in the averages of the above table, may be of contaminated waters, the increase in mineralization on this account is not sufficient to materially effect the average results. As shown in the table, the average mineralization of the water in the alluvial sand in the broad valley plain about Sparta, Tomah and Wyeville, is only about one third that of the water in the alluvial sand in the relatively narow valley of the La Crosse river, at La Crosse.

The higher mineral content of the underground water in the alluvial sand of La Crosse county as compared with that in the alluvial sand of Monroe county, shown in the table, is very probably due, as explained later, to the greater depth of the underground water at La Crosse as compared with that at Tomah and Sparta.

While very generally the water in the alluvial sand is lower in mineral content than that in the surrounding rock formation, in some localities, however, there is a strong tendency for a close similarity in mineral content from these sources. These conditions are illustrated in various counties, but are especially well shown in Monroe county where the mineral content of the water in the alluvial sand is much lower than that in the rock, and in La Crosse county, at La Crosse, where the average mineral content of the water in the alluvial sand is approximately the same as that in the sandstone.

QUALITY OF WATER IN LACUSTRINE CLAYS AND SILTS

In the eastern part of the state, adjacent to Lake Michigan and Green Bay, and in northern Wisconsin, adjacent to Lake Superior, are surface deposits of red clays of lacustrine and estuarine origin closely inter-

stratified with sands and gravels of alluvial origin. The lacustrine clays contain considerable amounts of calcium and magnesium carbonate, and the formation of clay and fine silt, as a whole, is generally dark bluish in color, the red clays prevailing at the surface being only the weathered and oxidized portion of the deposits.

These calcarceous clays and silts are relatively impervious and serve as the confining strata for the surface flowing wells associated with these formations. The quality of the water in the lacustrine clays and silts is very generally hard, on account of the lime content of the clays. In the glaciated parts of the state the calcareous lacustrine clays form a variable and often important portion of the drift deposits.

The lacustrine clays are also found to some extent in all parts of the state, including the driftless area and their presence in certain parts of the state doubtless tends to increase the mineral content of the ground-waters wherever they occur.

The occurrence of the red clays within the general area of the limestone portion of the state, adjacent to Lake Michigan, does not contribute materially to the relatively strong mineralization of the ground-waters in the eastern part of the state, and their occurrence within the area of the Lake Superior red sandstone probably does not contribute appreciably to the mineralization of the ground-waters adjacent to Lake Superior. Generally, however, the occurrence of the red calcareous clays in the soft water district of the state is likely to effect an important increase in the mineralization of the ground waters of the soft water district.

Summary of Quality of Water by Districts

Most of the wells in the northern half of the state are relatively shallow, generally less than 100 feet deep, the deepest wells being usually less than 400 feet deep. As the outer boundary of the state is approached, especially towards the south and southeast, there is a much greater range in the depth, the wells of relatively shallow depth being from 100 to 400 feet deep while those that penetrate through the entire thickness of water-bearing strata reach depths of 1,000 to 2,200 feet. It has not been found practical or convenient in Wisconsin, therefore, to separate the wells into shallow and deep wells in discussing the mineral content of the water. It is convenient, however, to compare the water in the surface deposits with that in the underlying rock. The wells in the surface deposits are always shallow while those in the indurated rock range from shallow to very deep.

The average mineral content of the wells in the surface deposits and in the indurated rock is indicated on the sketch Plate V and is summarized in the following table:

TABLE 35.—*Average mineral content of water from wells in the surface deposits and in the rock in Wisconsin.*

(Parts per million).

District.	Source.	Number of analyses.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg.)	Sodium and potassium (Na + K).	Carbonate radicle (CO_3.)	Sulphate radicle (SO_4.)	Chlorine (Cl).	Total dissolved solids.
North Central......	Surface deposits ...	69	8	22	7	8	45	22	5	121
District A.	Indurated rock.....	9	12	25	11	6	44	30	8	185
	Mean..................		8	22	8	8	45	23	5	122
South Central and Western	Surface deposits ...	51	7	42	20	10	109	19	8	224
District B.	Indurated rock	46	9	43	14	10	102	22	11	216
	Mean..................		8	43	17	10	106	20	10	220
East Central and Southwestern.....	Surface deposits ...	65	10	66	34	10	168	31	7	330
District C.	Indurated rock	95	6	66	36	11	174	33	11	339
	Mean..................		8	66	35	11	172	32	9	335
Eastern.............	Surface deposits ...	149	12	75	39	21	184	66	14	408
District D.	Indurated rock.....	113	11	88	32	30	157	184	15	466
	Mean		11	81	36	25	172	92	15	435

The table shows essentially the same degree of mineralization of the drift waters and of the underlying rock waters. It is only in the eastern part of the state, District D, that the mineralization of the water in the indurated rock is appreciably higher than that in the overlying drift of the same district.

The table also shows a gradual increase in mineral content of the waters in passing from the northern part, District A, to the eastern part, District D, of the state. This change in mineral content is progressive and not abrupt. For this reason the boundary lines between the various districts shown on Plate V are more or less arbitrary and nowhere as drawn do they represent any abrupt change in the mineral content. The total change in passing from one district to the next adjoining is not great, but relatively slight, a difference of only 100 parts per million as measured in total solids, yet the percentage increase is sufficiently pronounced and so persistent as to enable one to readily divide the state into the various districts as described. In only a few other states in the Union, such perhaps as those in the crystalline areas of New England, are the waters so low in mineral content.

The average mineral content of the underground waters in Wisconsin per area is shown in the following table:

TABLE 36—*Average mineral content of underground water of all wells in Wisconsin.*

(Parts per million.)

District.	Area in square miles.	Area in percentage.	Number of analyses considered.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium. (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.
North Central District, A..........	20,000	36.7	78	8	22	8	8	45	23	5	122
South Central and Western District, B	18,300	33.6	97	8	43	17	10	106	20	10	220
East Central and Southwestern District, C..........	9,900	18.2	166	8	66	35	11	172	32	9	335
Eastern District, D..	6,250	11.5	262	11	81	36	25	172	92	15	435
State..................	54,450	100.00	597	8	44	19	11	103	32	9	230

This table shows the total area as well as the percentage area of each of the districts into which the state has been divided and also the average mineral content of all underground water in each district and for the entire state. While the average mineral content of the underground water in the large soft water district A is 122 parts per million and that in the small very hard water district D is 435 parts per million, the average for the entire state is only 230 parts per million. As *soft, hard,* and *very hard* waters are defined in this report, soft water is characteristic of a little over one-third, hard water of about one-third, and very hard water of a little less than one-third of the state.

It should be noted that the highly mineralized and salt waters from 18 localities of the state are not considered in the calculations shown in this table. Considered per analysis the highly mineralized waters would appreciably increase the average mineralization indicated, but considered per area affected, the influence of the salt waters in the calculations would be very slight. In obtaining water supplies in Wisconsin, the highly mineralized waters can usually be avoided, hence average conditions likely to be encountered are believed to be best represented by the averag analyses shown in the table.

SUMMARY OF QUALITY OF WATER BY GEOLOGICAL FORMATIONS

The mineral content of the ground water in each geologic formation varies in different parts of the state. This fact is illustrated on comparing the mineral content of water in the sandstone mainly Upper Cambrian in the various districts of soft and hard waters already described. The average mineral content of the water in the sandstone is shown in the following table:

TABLE 37. *Average mineral content of water in the sandstone (mainly Upper Cambrian).*

Parts per million.

Locality.	Usual depth of wells in feet.	Number of analyses.	Silica (SiO_2)	Calcium (Ca).	Magnesium. (Mg).	Sodium and potassium. (Na+K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_4).	Chlorine (Cl.)	Total dissolved solids.
General outcrop area of the sandstone	200–500	42	11	41	18	8	98	21	8	209
The sandstone under the Galena-Platteville limestone	500–1000	98	8	67	34	15	168	40	12	349
The sandstone under the Niagara limestone	1000–2000	47	12	107	29	28	143	181	12	509

In the above table is indicated the position of the sandstone with reference to the overlying formations, and the usual depth of wells below the surface. The average mineral content of the sandstone in its area of outcrop or where overlain only by the Lower Magnesian limestone on the upland divides is 209 parts per million; where the sandstone underlies the general area of the Galena-Platteville limestone, the mineral content of the sandstone water is 349 parts per million; and where the sandstone underlies the Niagara limestone the Cincinnati shale and the Galena-Platteville limestone the mineral content is 509 parts per million. There is, therefore, a progressive increase in the mineral content of the water in the sandstone in passing from its area of outcrop, in central Wisconsin, to its position at greatest depth below the surface, in eastern Wisconsin.

The mineral content of the water in the surface formation also varies in different parts of the state. In Table 33 the mineral content of the water in the surface deposits is shown to progressively increase from 121 parts per million to 408 parts per million in passing from District A to District D.

It is impossible to make any instructive comparison of the mineral content of the water in the Galena-Platteville limestone over any extended area, as this formation is confined to only the southern and eastern parts of the state, and most of the analyses of water from this horizon are from its area of outcrop in the southwestern part of the state. While this formation extends through the eastern part of the state, underneath the Cincinnati shale and Niagara limestone, it is not drawn upon for water supplies, as the shallow wells in this region get their supply from the drift and the Niagara limestone, immediately underlying, while the deep wells usually penetrate clear through the Cincinntai

shale and the Galena-Platteville, and draw their suply from the underlying Potsdam sandstone. There can be little doubt, however, that the water in the Galena-Platteville, in eastern Wisconsin, under the Niagara, is more highly mineralized than that within its area of outcrop farther west, as indicated by the fact that the water-bearing strata, both above and below the Galena-Platteville in the eastern district, D, are higher in mineral content than that of the latter farther west.

It is also obviously impossible to make any instructive comparison of the mineral content of the water of the Niagara limestone over any extended area, as this formation is confined to only a relatively narrow belt on the eastern border of the state. It is worthy of note, however, that the mineralization of the water in the Niagara is appreciably higher than in the Galena-Platteville and other limestone formations, farther west and northwest in the state.

Correlation of the Mineralization of Underground Water by Districts and by Geologic Formations

It is shown, in the above summarization of the mineral content of water by districts, that there is a progressive increase in the mineral content in passing from the north-central district of the state, District A, to the outer border, and especially to District D, the eastern border of the state. It is also shown that there is a progressive increase in the mineral content of water by geologic horizons in passing from District A to District D, in all those formations, such as the sandstone and the surface deposits, that extend throughout these districts.

If the increased mineralization of the water in the sandstone alone were considered, the conclusion might be reached that such increase was due to the increased depth of the sandstone below the surface, in passing from District A to District D. However, it is to be observed that there is also a progressive increase in the mineralization of the water in the surface deposits in passing from District A to District D, and furthermore, the increase in the surface deposits very generally is nearly equal to that which takes place in the underlying sandstone or other underlying water-bearing formations as illustrated in the geologic section, Fig. 16.

The mineralization of the water in any particular geological formation appears, therefore, to depend upon some underground geologic condition, characteristic of the district or locality as a whole, rather than upon the local chemical character or the relative position of the formation in the geologic section of the locality. The progressive change in

mineralization varies in a horizontal direction with the geographic district rather than in a vertical direction with the geologic column.

The underground water condition that progressively changes, in passing from the north central part to the outer part of the state, is the gradual increase in the thickness and depth of the water-bearing formations. The least thickness of water-bearing strata, and consequently the most shallow depth of the body or sea of underground water, is in the north central part of the state, District A, characterized by soft water. The greatest thickness of water-bearing strata, and consequently the greatest depth of the sea of underground water, is in the eastern part of the state, District D, characterized by very hard water. In the intervening districts, between the north central and the eastern, are intermediate thicknesses of the strata and corresponding intermediate depths of the sea of underground water.

Hence the inference is drawn that the controlling factor in the mineralization of the water in the several districts is the depth of the sea of underground water in the districts. The chemical character or the relative position of the water-bearing strata in the geologic section of the district, is, apparently, only an unimportant or minor factor in effecting the degree of mineralization.

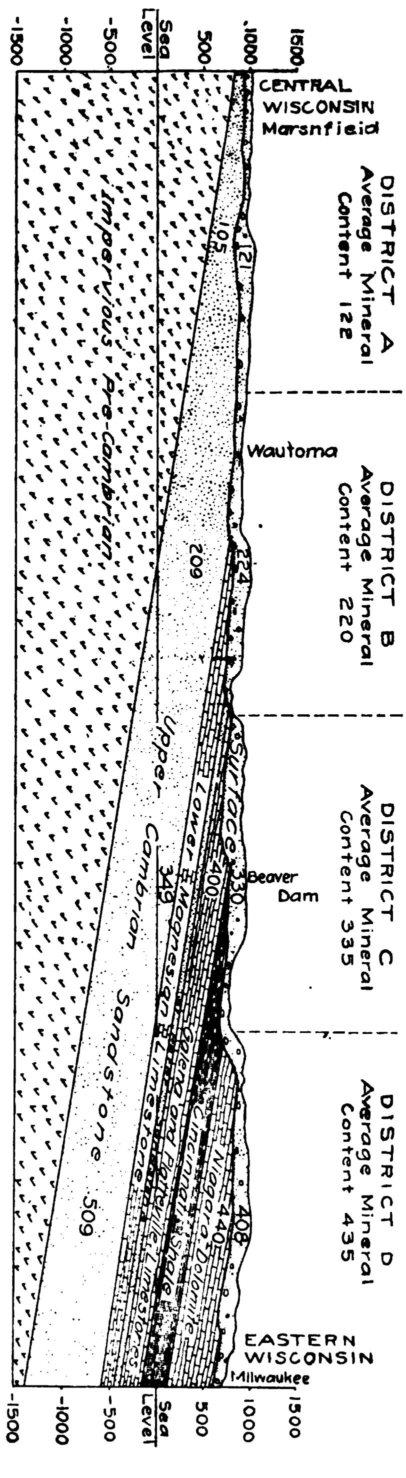


Fig. 16.—Section illustrating the position of the geologic formations and the average mineral content of the underground water of each in the various districts.

The relation of the progressive increase in the mineralization of the underground water to the progressive increase in the depth of the sea of underground water in passing from north-central to eastern Wisconsin is illustrated in the diagram, Fig. 17.

That this progressive increase in mineralization with increasing depth of the sea of underground water also continues beyond the border of the state, is shown by a comparative study of the mineral content of the underground water in the adjoining states so far as these can be conveniently examined. In Iowa, the mineralization of the underground water[1] by districts has been described, and while the basis of the formation of the districts in the report of the water supplies of Iowa is not the same as that adopted for Wisconsin, the increase in the mineral content of the waters with depth of the underground water can be readily shown for purpose of comparison with the geological districts in Wisconsin.

The increase in mineralization, with increased depth of the sea of underground water, in passing from Central Wisconsin to Southwestern Iowa, is shown in the following table:

TABLE 38. *Showing relation of depth of sea of underground water to the mineralization of the underground water in Wisconsin and Iowa.*

District.	Approximate depth of sea of underground water or thickness of the water-bearing strata.	Average mineral content in parts per million.	
Central Wisconsin District A..	100 to 200 feet.	Surface deposit wells....	121
		Rock wells................	185
Western Wisconsin, District B	400 to 800 feet....................	Surface deposit wells....	224
		Rock wells................	216
Southwestern Wisconsin, District C.........................	800 to 1,600 feet.................	Surface deposit wells....	330
		Rock wells................	339
Northeastern Iowa..............	1,600 to 2,000 feet...............	Shallow wells............	388
		Deep wells................	351
Central Iowa....................	About 3,000 feet................	Shallow wells............	873
		Deep wells................	1,759
South Central and Southwestern Iowa......................	About 4,000 feet................	Shallow wells............	1,587
		Deep wells................	3,657

The deep wells in the districts of Iowa are defined as those that penetrate at least the St. Peter sandstone and all other wells more than 700 feet deep. Shallow wells are those in the drift and in rock generally less than 700 feet deep.

[1] Geol. Survey of Iowa. Vol. 21, p. 205–211.

The change in mineral content in Iowa[1] has been described as abrupt rather than progressive and yet this abrupt change to be observed in a certain portion of Iowa is of relatively minor importance when the total change in mineralization in passing from the more shallow sea, in northeast Iowa, to the deeper sea of underground water, in southwest Iowa, is taken into consideration.

The table clearly shows a close conformity in the increase in mineral content with the increase in depth of the sea of ground waters in passing from the very shallow sea of ground water in central Wisconsin to the deep sea of ground water in southwestern Iowa.

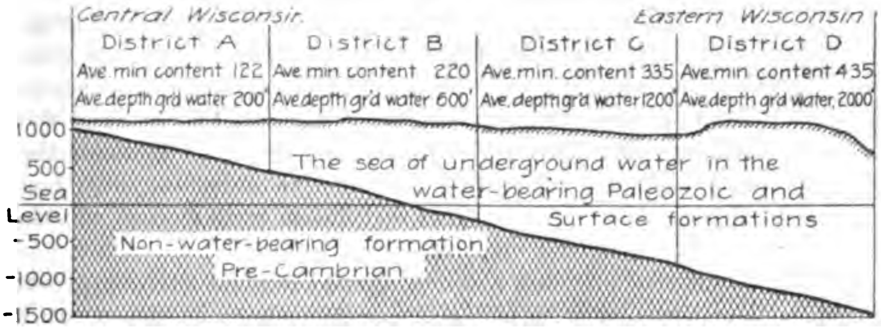


Fig. 17.—Diagram showing the relation of the progressive increase in the mineral content of the underground water to the progressive increase in the depth of the underground water.

A table could be arranged showing the similar progressive increase of mineral content with increase in depth of the sea of underground water, in passing from Central Wisconsin westward along the southern border of Minnesota,[2] or the norther border of Iowa.[3]

The progressive increase in mineral content, with increased depth of the sea of underground water, is likewise shown in passing from the northern part of Wisconsin southward to the southern part of Illinois[4]. In southern Illinois, there is a slight arching of the strata and a consequent development of shallow depth of groundwater over the arch which condition of underground structure appears to be reflected in the lower mineral content of the ground water over the arched district. In a general way, however, the mineral content of the underground waters of Illinois progressively increases in passing from the

[1] Iowa Geol. Survey, Vol. 21, p. 205.
[2] Underground Waters of Southern Minnesota, U. S. Geol. Survey. W. S. P. 256, pp. 61–78.
[3] Opus cited. p. 205–211.
[4] Illinois Water Survey, Bulletin, No. 4.

more shallow sea of underground water, in the northern part of the state, to the deeper sea, in the southern part.

The close relationship in the degree of mineralization to the depth of the sea of ground water in any district or region is, therefore, well illustrated outside of, as well as within Wisconsin. The various factors controlling the mineralization of ground water cannot be entered into in this paper but may be taken up for a more complete discussion at another time.

It may be sufficient to state, that the deeper the sea of underground water, the more important become the sulphates and chlorides, and the less important, relatively, become the carbonates or bicarbonates. There are a great many factors that influence the mineralization of ground waters, and while change of pressure and temperature due to change in depth of the sea of ground water, are relatively important, they may sink to secondary importance, because of variable underground geological conditions that characterize the various districts. In this respect, reference should be made to pressure other than that directly due to weight of the water column, such as that due to earth stresses, to weight of rock, and to content of natural gas.

For the present purposes it is only needed to point out that pressure other than that due to weight of the water column is apparently not important in Wisconsin. In regions of natural gas, however, as in parts of Indiana, Illinois and Ohio, where very highly mineralized salty water is the invariable associate of natural gas, the factor of gaseous content of the underground water is probably a very important and dominating factor to be considered.

It will be observed, therefore, from the foregoing discussion of the gradation in the mineralization of the underground water shown by the several districts of Wisconsin, that the mineral content is very apparently closely related to the depth of the sea of underground water in each district, the general increase in mineralization being in conformity with the general increase in depth of the sea of underground water. While there are many other factors modifying mineralization, the increase in pressure and temperature due to the increased depth, and the direct influence of these factors on the rate of diffusion of salt solutions throughout the sea of underground water, appear to be the controlling factors in the mineralization of the underground water of the several districts into which the state has been divided.

To whatever extent the mineralization of any water varies from the average normal of the district, to that extent the mineral content may be stated as being influenced by local underground geologic conditions

other than those directly or indirectly affecting the local pressure and temperature. Among other important modifying factors and conditions that may be mentioned are the differences in the chemical composition of the rock, and the changes of variable conditions favorable or unfavorable to the underground circulation of water and to the molecular diffusion of mineral solutions, in both horizontal and vertical directions.

But without further discussion of the causes of mineralization, it seems far more important, from the practical point of view, that the mineral content of any underground supply should be considered with respect to its environment in the particular district in which it occurs, rather than with reference to its source in any particular geological horizon. The underground water of any particular geological stratum cannot be dissociated from its environment unless impervious strata of wide extent separate it from all associated water-bearing strata. This fact is well illustrated by the low mineral content of water in the Upper Cambrian sandstone in Central Wisconsin as compared with its high mineral content in the same formation in Iowa, or by the low mineral content of the water in glacial drifts in Central or Eastern Wisconsin as compared with the high mineral content in the drift of Central and Western Iowa. The mineralization of the ground water of any water-bearing strata in a district of shallow ground water, therefore, is quite different from that of the same water-bearing strata in another district of deep groundwater, and this characteristic applies equally well to shallow water-bearing strata and to deep water-bearing strata.

It is incorrect, therefore, to state, as is often done, that the mineral content of the water in a limestone, sandstone, or shale is typical for limestone, sandstone or shale in general; it is typical or characteristic only for these formations in the same district, or in another district in which the general conditions of pressures and temperature affecting the underground water are equivalent. The principal of the close dependence of the mineralization of the groundwater in any water-bearing strata, upon its environment is important and should not be overlooked in making a comparative study of the underground waters of adjacent districts and regions.

Quality of Underground Water in the Pre-Cambrian Formations.

In the foregoing discussion of the relation of the degree of mineralization of the underground waters in the geologic horizons of the various districts of the state, very little or no consideration has been given

to the underground waters of the Lake Superior red sandstone or of the Pre-Cambrian crystalline formations. This lack of consideration is partly due to the fact that these formations are of relative unimportance as sources of water supply, and in part to the fact that very few mineral analyses of waters from these formations are available.

However, the same factors very probably affect the mineralization of the relatively meager underground waters of these older formations as affect the very abundant underground waters of the later Paleozoic formations of sandstone and limestone, and the superficial deposits.

With respect to the quality of the underground water in the Lake Superior sandstone, it is usually very highly mineralized, so far as available analyses and numerous qualitative tests appear to indicate. The red sandstone in the Lake Superior basin probably attains a very great thickness, usually estimated to be over 20,000 feet, hence so far as the red sandstone beds are water-bearing and hold underground water of great depth, a high degree of mineralization should characterize the underground water throughout this very thick formation. The brackish and salty waters obtained from the red sandstone at Ashland and Superior are very probably, therefore, not of unusual or rare occurrence but indicate the usual brackish quality for the entire red sandstone formation.

With reference to the Pre-Cambrian crystalline formations, including the Keweenawan trap and the Huronian metamorphic sedimentaries, all of which are of complex structure and are relatively impervious formations, they are affected by somewhat different underground conditions from those that affect the relatively undisturbed and semi-porous Lake Superior sandstone. There are usually only meager amounts of underground water in the Pre-Cambrian formations. While large amounts of water may be pumped from some of the iron mines in the Pre-Cambrian districts, this mine water, in most cases at least, is probably largely drawn down from the surface water-bearing horizons of the locality.

The impervious character of the Pre-Cambrian rock, the water contained being confined only to the fractures and other open spaces so far as these are developed, prevents the ready circulation of the underground waters and greatly hinders the movement of mineral solutions by osmosis.

In the superficial zone of abundantly fractured crystalline rock, usually within 100 feet of the surface, the groundwaters are likely to be only slightly mineralized, due to the shallow depth of the ground water.

In many instances however, there may occur in the Pre-Cambrian deep underground waters held under hydrostatic pressure, and where such are encountered, usually in deep mining explorations, they are likely to be highly mineralized, as are the deep-seated waters which characterize the more abundantly water-bearing horizons of the Paleozoic strata.

Examples of especially highly mineralized water in the Pre-Cambrian are the salt water encountered in the bottom of the Florence iron mine and the salt waters[1] very generally found in the deep iron and copper mines of Upper Michigan. These highly mineralized waters in the Pre-Cambrian, are usually, if not always, derived from deep lying sources, and are very probably primarily due to their physical environment, and only secondarily to the general chemical character of the rocks in which they may be imprisoned.

PROSPECTING FOR WATER SUPPLIES WITH RESPECT TO MINERAL QUALITY

The prospecting for the best available water supplies in any locality is important, and is not as fully appreciated as it should be by many of those who have charge of securing supplies for manufacturing plants or cities. The large corporations, such as the railroad companies, usually appreciate the value of securing the best available supplies for industrial use, and for this reason, maintain laboratories for testing water and for the purpose of determining the proper treatment to be applied to supplies in case treatment is necessary. Many manufacturing plants, however, pay little attention to the character of the water, and in many instances, use supplies in boilers that have been rejected for locomotive use by the railroads.

In some instances, it is not possible, for local plants to obtain a better supply with lower degree of hardness, but in most instances, better supplies from an available source are readily obtainable. In case good supplies are not obtainable, special treatment of the water should be applied, and for the determination of the proper treatment mineral analyses are necessary which can be furnished by chemical laboratories at a relatively low cost ($10 to$20), as compared with the saving resulting from the treatment of the supplies. The general uses of water and processes of treatment are given in Chapter VI.

With respect to the securing of the best available supplies for industrial use in various localities the descriptions of the local county supplies should be examined, and the quality of the water, as given in the county tables of mineral analyses of water, should be studied.

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[1] A. C. Lane, "Mine Waters" Lake Superior Mining Institute, Vol. XIII, p. 63–152. 1908.

The mineral analyses quoted may be considered as fairly representative of the character of the local supplies. A larger number of analyses, especially for certain parts of the state, are perhaps desirable, and yet the average conditions appear to be fairly well indicated by the data presented for the various parts of the state. That the mineral analyses compiled are sufficient for judging the quality in the various districts appears to be well illustrated by the fact that only slight changes in an earlier calculation of the average mineral content of the water in the various districts, and the geological strata, were necessary, after compiling an additional number of about 250 analyses which later became available.

In the earlier calculation, 29 analyses of water from the Upper Cambrian (Potsdam) sandstone, in the outcrop area of this formation, gave an average total mineral content of 210 parts per million, and in the final calculation, 42 analyses gave an average total mineral content of 209 parts per million.

In the earlier calculations, 52 analyses of sandstone water, under the Galena-Platteville limestone, gave an average total mineral content of 367 parts per million, while the final calculation of 98 analyses, gave an average of 349 parts per million.

The first calculation of the average mineral content of 13 analyses of water in the Galena-Platteville limestone gave an average of 397 parts per million, while the final calculation on 20 analyses gave an average of 400 parts per million.

The first calculation on 12 analyses of water in the Niagara limestone gave an average of 430 parts per million, and the final calculation on 35 analyses gave an average of 440 parts per million.

The analyses compiled therefore appear to be representative, and the average mineral content, as well as the general range in mineral content, as described, can be taken as a sound basis for estimating or judging the probable quality of supplies obtainable in the various districts, and counties of the state.

While the hardness of the underground water of all water-bearing strata progressively increases in passing from District A to District D, the water-bearing or geologic strata in each district have an individuality of their own which should be fully understood by those in search of the best available supplies in any locality, county or district. An industrial plant in District D, in eastern Wisconsin, will not be able to get as soft a water supply as a plant in District B or C, nearer the central part of the state, yet a much better supply can often be obtained in some of the water-bearing strata than in others in District D.

A comparative study of the mineral content of the water of the several important water-bearing strata has already been presented, but certain generalizations are well worthy of repetition here in connection with the subject of prospecting for water supplies.

1. The water of relatively shallow wells in alluvial sand is very generally less mineralized than that in the associated indurated rock of the same locality, in all districts.

2. The water in the sandstone group (Upper Cambrian and St. Peter sandstone, and Lower Magnesian limestone) is very generally less mineralized than that in the overlying Galena-Platteville limestone within the general outcrop area of the Galena-Platteville, mainly in District D. Or stated contra-wise, the mineral content of water in the Galena-Platteville limestone is generally higher than that in the underlying sandstone in the outcrop area of the Galena-Platteville. This relationship is shown in table 31, the average content of water in the Galena-Platteville being 400 parts per million and that in the underlying sandstone 352 parts per million.

3. In certain counties, where limestone drift is abundant overlying the sandstone, as in Dane and Rock counties, the mineral content of the water in the drift is generally slightly higher than that in the underlying sandstone.

4. The mineralization of the underground water in the important water-bearing strata of District D, in the general area of the Niagara limestone in eastern Wisconsin, appears to be consistently different for each water-bearing group, the average mineral content generally approximating 408 parts per million in the drift and associated surface deposits, 440 parts per million in the Niagara limestone, and 509 parts per million in the underlying group of water-bearing sandstone, the Potsdam and St. Peter formations. (See Fig. 16.)

5. The mineral content of the water of creeks and rivers varies greatly, depending much on the stage of the river. (For description of the chemical composition of river and lake waters see the following chapter, Chapter VIII). In general, also, the waters of creeks and rivers are much lower in mineral content than the local underground waters, the former usually being from 25 to 50 per cent lower in mineralization than the underground waters of the same locality or district. (See p. 214).

6. The water of deep inland lakes, those over 50 feet deep, are very generally less mineralized than the streams that flow into them, while the water of shallow lakes is much the same as that of their affluents.

7. The water of Lake Superior is soft, and low in mineral content, about 60 parts per million, while that of Lake Michigan is medium hard,

though low in mineral content, containing about 134 parts per million. The water of the Great Lakes is much lower in mineralization than that of the surrounding body of underground water or that of the streams flowing into them, apparently having only an indirect or somewhat remote relation to the degree of mineralization of the surface water of the streams or of the underground waters of the adjacent rock formations.

The relatively slight differences in the average mineralization of certain water-bearing strata above pointed out, may or may not be important, for this will depend much upon the specific use of the water or the quantity required. There are also some exceptions to the general averages above given for various localities which should always be taken into consideration.

If the supply from the overlying water-bearing strata is unusually high in mineral content, as compared with the average in such strata, the well should be sunk to the next underlying strata in case the average mineralization for the underlying strata is appreciably less than that already obtained in the overlying strata. Likewise, if a supply is obtained from the overlying strata with a much lower mineral element than the average, and also lower than the average for the underlying usually less mineralized strata, then it is not advisable to drill deeper in search of a better supply.

For each locality and district the average quality of water in each water-bearing strata should be understood, for it is only on the basis of the average conditions that predictions can be made concerning the quality of water most likely to be obtained in each locality. To ascertain the average quality of the water in various formations, counties and districts, the Tables, 22 to 38, and the illustrations, Pl. IV, and Figs. 16 and 17, should be consulted.

The practical aid obtainable in prospecting for water supplies will depend very largely upon the intelligent use of the data presented in this report, relating to the quantity, the chemical composition, and the general character of the water from the various geologic sources in each county and locality described.

CHAPTER VIII.

SURFACE WATER SUPPLIES AND THEIR CHEMICAL QUALITY

Besides the underground water, including that derived from shallow wells, deep artesian wells, and springs, an important source of water supply for domestic use and drinking purposes is the surface water of lakes and streams. In rural communities the water from lakes and streams is generally used only for stock, the water for drinking and domestic use being drawn from underground sources. Cities, however, especially those of large population, usually draw upon the surface waters for their public supplies.

Many of the cities along the shore of Lake Michigan, such as Milwaukee, Racine, Sheboygan, and Kenosha, draw their public supply from Lake Michigan; and many of the inland cities, such as Portage, Oshkosh, Fond du Lac, Stevens Point, and Merrill, draw their supplies from the rivers or lakes on which they are situated. Considering the total supply of all potable water, the surface waters are a less important source of supply in Wisconsin than the underground and artesian waters. Considering only the public supplies for city populations, however, the surface waters are a much more important source of supply than both shallow and deep underground waters. For this reason, therefore, a statement of the general character of the surface waters seems warranted in any discussion of the water supplies of the state.

SOURCE OF THE SURFACE WATER

The source of the surface water is directly from rainfall upon the surface of lakes and streams, and indirectly from the surface run-off, and from underground waters through seepage, and from the flow of springs.

The principal problem connected with surface water supplies is not concerned with the quantity available and the method of obtaining and distributing the supply, but is mainly concerned with the quality of the supply and its freedom from sources of contamination.

CHARACTER OF SURFACE WATER

Some impurities are absorbed by the rain as it falls through the air, many of which, however, are lost as soon as it comes into contact with the ground; but in its course over the surface of the ground as surface drainage or as run-off in streams or rivers many more impurities are gathered up and carried along either as matter in suspension, or as matter in solution. The suspended matter is both inorganic, or mineral, such as sand, clay and various pulverized minerals, and organic matter, both animal and vegetable. The animal matter in suspension includes living microscopic animals, dead fish and other animals that lived in the water; decayed animal refuse; manufacturing wastes such as wool scourings; blood from slaughter houses, etc.; and the excrement from public and private sewers. The vegetable matter that is carried by the surface water includes such matter as dried leaves, grass, and flowers, decayed wood, peaty matter, algae and other living plant life, including bacteria and disease germs; wastes from pulp and paper mills, linen mills, breweries, etc.

The dissolved matter in the surface waters is both gaseous and solid, from inorganic as well as organic sources.

For various reasons the use of surface waters, particularly from the streams flowing through densely populated districts or through cities, is a menace to health, unless they are subjected to some method of purification. As a rule the lake waters, especially the waters of the Great Lakes, are naturally of much better quality than running waters that carry off the surface waters from the near by populated land areas.

WATER SUPPLIES FROM RIVERS

A number of cities in Wisconsin, such as Stevens Point, Merrill, Portage, and Rhinelander on the Wisconsin river, obtain their water supply, wholly or partly, from the rivers, upon which they are located. Many small cities of the state use river water for fire protection only.

Invariably, these rivers are used as a sewer, as well as a source of water supply. In many parts of the country, because of the large amounts of water required by large cities or because of unfavorable conditions for obtaining an underground water or a lake supply, the rivers are the only adequate available source of supply, and will always remain so. But this condition does not appear to be true of Wisconsin cities at the present time. All those cities now obtaining the whole or a part of their supplies from rivers could readily obtain adequate supplies from underground sources.

It is possible to purify sewage before discharging it into the rivers. If all cities and towns purified their sewage, and if all manufacturing plants, which often contribute more to the pollution of the streams than do the cities, purified their waste and refuse, the rivers would be more desirable as sources of public water supply.

Bacterial Condition of Flowing Streams

The development of bacterial organisms including disease germs in surface waters directly depends upon the amount of organic matter which is available as food for these organisms. It is a well known fact that the bacterial pollution of a stream is always greater during high water stages, when the waters are turbid and carry large amounts of suspended matter than in low water stages when the water is clear. Much of the bacteria, of course, is washed into the streams from the soil and land surface during heavy rains. According to investigation of Johnstone[1] the bacterial content of uninhabited streams, like the Saguenay in Canada, is not materially different from that of rivers flowing through farming regions. However, where a stream flows through a city or town of considerable size and receives the sewage of the same, the extent of pollution is greatly increased. This fact is well illustrated by the following conidtions, described by Prausnitz[2], of the Isar river, at Munich in Germany:

Table 39. *Bacterial content of Isar River, Germany.*

	Number of bacteria per c. c.
Above the city of Munich	531
150 feet above sewer outfall	1,389
Directly opposite sewer outfall	121,861
450 feet below sewer outfall	33,459
Ismaning (8 miles below sewer outfall)	9,111
Freising (20 miles below sewer outfall)	2,378

This table not only shows a marked increase of bacterial content of the river at Munich, but also shows that a large part of this pollution is lost in a comparatively short time, by the time the water reaches Freising, 20 miles below. In this instance about 50 per cent of the bacteria introduced in the sewage was eliminated in a flow of about 12 miles. A number of American streams have been studied recently by sanitary sur-

[1] Hyg. Rund. B. V. p. 796.
[2] Quoted from Public Water Supplies, Turneaure & Russel, p. 148.

veys. A most comprehensive study of the effect of the Chicago Drainage Canal on the water of the Illinois river has been made, a part of the result being indicated in the following table[1]:

TABLE 40. *Chlorine and Bacterial Determination of Water in Illinois River.*

	Miles below Bridgeport.	Chlorine, parts per million.	Bacteria, per c. c.
Bridgeport	0	119.2	1,245,000
Lockport	29	117.4	650,000
Joliet	33	104.8	486,000
Morris	57	68.1	439,000
Ottawa	81	58.5	27,400
La Salle	95	46.1	16,300
Henry	123	44.2	11,200
Averyville	159	40.9	3,660
Wesley City	165	40.1	758,000
Pekin	175	38.4	492,600
Havana	199	36.2	16,800
Grafton	318	18.3	10,200
Mississippi river at Grafton	....	2.8	7,600

The extent of the natural purification of the Illinois river can be seen from the above table, table 40. The decrease in amount of chlorine is steady all the way from Bridgeport, where a large proportion of the Chicago sewage is present, to the Mississippi river. The bacterial diminution is also steady down the river, until the river receives at Wesley City a large amount of refuse from Peoria.

There are various factors entering into the problem of the pollution and the purification of flowing stream waters that cannot be touched upon in this report. Enough has been said, however, to show that surface water supplies are naturally always subjected to conditions of contamination and pollution, and that while self purification of the waters takes place by the action of dilution, sedimentation and sunlight, some effects of the pollution always remain.

It has been a disputed question among sanitary engineers whether, in general, it is more economical to purify the sewage before emptying into the rivers, or to purify the water supplies obtained from the rivers. The answer to this problem very probably would depend very much upon local conditions.

But in general, the inevitable tendency is toward a requiremnet of the treatment and purification of the sewage before its disposal into natural water ways of the state, not only for the purpose of preventing the pollution of possible sources of potable water supplies, but also for the purpose of preventing the development of local nuisances, such as

[1] Quoted from Public Water Supplies, Turneaure & Russel, p. 151.

the discoloration of the water, the general occurrence of refuse floating on the water, the deposition of sewage mud on the bed of the river, and the production of offensive odors. All of these nuisances tend to make the river undesirable for bathing, boating, fishing, navigation, business, residence, and in various other ways less useful to the public and to those living in the locality.

Practically all of our cities and villages are located upon waterways, either rivers or lakes, and the practice has been to empty the city sewage into these waterways regardless of the health and convenience of other communities. In recent years, many of our Wisconsin cities have come to realize the danger and folly of such action, not only on account of the public health, but also because of its effect upon the value of property; and as a result, methods of sewage purification have been installed by the more progressive and enlightened communities.

These methods of sewage treatment installed, such as septic tanks and filter beds, are not intended as a rule to completely purify the sewage, but mainly to bring it to a state of reduction in the number of bacteria present and put it into a more soluble form tending toward a more rapid purification by the stream[1].

In the description of local water supplies by counties the method of sewage disposal by the various cities is briefly indicated. It will be seen that many of our cities empty their raw sewage, without treatment, into the natural water ways of the state.

Water Supplies from Lakes

While the many lakes of Wisconsin offer an abundant supply of surface water for public or private use, only the largest cities, mainly those on Lake Michigan, draw upon lake water for their supply. Lake Michigan, therefore, is the most important source of lake supply, the other lakes drawn upon being Lake Superior by the city of Ashland and Lake Winnebago by Oshkosh. As already stated, because of the large size of the city of Milwaukee and other cities on Lake Michigan, the lake supplies are the most important source of public water supplies in the state.

General Character of Lake Supplies

The waters of lakes are subjected to the same general influences as the surface waters of rivers, but in general the waters of an open expanse, such as one of our inland lakes, are less likely to show marked pollution

[1]For a more complete discussion of Wisconsin's sewage plants, see Davis Bowles, Bulletin Univ. of Wis., No. 331.

than flowing streams, because in quiet waters there is less suspended matter and therefore less turbitity and less food for bacterial organisms. In large bodies of water, such as the Great Lakes, the effect of pollution is mainly restricted to the shore regions.

Inland Lakes.—In general the water supply from small lakes may be quite unlike that obtained from one of the Great Lakes. In small lakes and artificial reservoirs some satisfactory protection of the catchment area is necessary, and such conditions as the stagnation and putrification of the bottom water and the growth of organisms in the top water affect the character of the water supply. These periods of stagnation in the inland lakes in which there is no vertical circulation occur in the winter and summer. Between these periods there is an "overturning", that is, a vertical circulation due to changes in temperature.[1]

In the following tables, 41, 42, 43 and 44, much information concerning many of the inland lakes of Wisconsin is summarized. The features of all the lakes referred to in the tables have been investigated to a variable extent by the State Survey, and the results published in a recent report, Bulletin XXVII, and to this work the reader is referred for further detailed information concerning the natural history of these lakes.

The many inland lakes of the state are of interest as available sources of water supply for potable and industrial purposes. In Table 41, the data concerning the surveyed lakes of southeastern Wisconsin are summarized, the location, areal extent, depth, volume, development, length of shore line, mean slope of bottom, elevation above sea level, and reference to the published hydrographic maps are given.

In Table 42, the surveyed lakes of southwestern Wisconsin, Table 43, the lakes of northeastern Wisconsin, and in Table 44, the lakes of northwestern Wisconsin, are given data concerning the location, length, breadth, area, and maximum known depth.

Great Lakes.—The water in the Great Lakes at 5 to 10 miles from the shore is generally crystal clear and essentially pure. The distance to clean water from the shore, however, depends upon the nature of shore deposits and the depth of water. The shore deposits of both Lake Superior and of Lake Michigan are often red clay, and the shallow water over these red clays is often rendered turbid during storms. The water in Lake Superior at Superior and Ashland is often turbid 6 to 10 miles from the shore.

There is a marked diminution in the germ content of the water in

[1]See "Inland Lakes", Birge and Juday, Bull. Wis. Survey, No. XXII.

* The areas of the lakes marked with an asterisk were determined by Mr. C. B. Stewart, Consulting Engineer, Madison, Wis.

						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	73.8
Wild Goose..........	34	XVII	Polk..........	1.53	0.95	NW-SE	1.03	0.64	1.08	0.40	256.0	4.5	14.8

							[illegible]	[illegible]	[illegible]	1.40	396.0	33.5	73.8
Wild Goose..........	34	XVII	Polk..........	1.53	0.95	NW-SE	1.03	0.64	1.03	0.40	256.0	4.5	14.8

large lakes as the distance from the shore increases. Except in the case of inflow of rivers of considerable size, the evidence of land pollution does not extend far, because out in the deep quiet water the matter in suspension falls to the bottom where the organisms lose their vitality.

The area, depth, and elevation of the lakes, Superior and Michigan, are given in the following table:

TABLE 45. *Area, depth and elevation of Lakes Superior and Michigan.*

	Area in square miles.	Maximum depth in feet.	Elevation above sea level.
Lake Superior	31,200	1,008	602
Lake Michigan	22,450	870	581

Lake Superior is the largest body of fresh water on the globe. Both lakes are drawn upon for public water supplies by many of the cities on the lake shores.

While there is a strong tendency for the natural purification of the waters of the Great Lakes, the effects of sewage pollution are matters of great importance for the cities on the Great Lakes as invariably the cities put their sewage into the same water from which their supplies are taken.

There is not so much danger of one city polluting the water supply of an adjacent city along the shore, as there is of a city polluting and infecting its own supply. There is often, also, more danger of the smaller cities mingling their sewage with their own water supply than of the larger cities, as in the smaller cities less money is available for water works; their intakes do not go out so far into the lake; and their sewers are therefore more likely to discharge near the intake. Milwaukee, population 373,857, draws its water supply from Lake Michigan, the present intake extending out 8,500 feet at a depth of 58 feet. Kenosha draws its lake supply from a 5,000 foot intake, at a depth of 35 feet. Sheboygan obtains its lake supply from 3 intakes at depths of 12, 27 and 47 feet. None of these cities treat the sewage in any manner before emptying it into the lake. In general no serious trouble has been directly attributed to the water supply for these and most other Wisconsin cities using lake supplies. And yet the experience at Chicago and the adjacent cities and towns in the North Shore district[1] seems to indicate that the utmost care and watchfulness should be applied in safeguarding the wa-

[1] See Eng. News, Vol. 64, p. 325, "Quality of Lake Michigan as a Water Supply for the North Shore District."

ter supply of those cities that put their raw sewage into the same water from which their supplies are taken.

Chemical Quality of Surface Waters

The mineral content of the waters in our lakes and rivers, ranges from 16.4 parts per million in the water of the lake at Woodruff, Vilas county to over 200 parts per million in many of the rivers of the eastern part of the state. The waters of lakes and rivers are somewhat unlike in their mineral content, hence they are described separately.

RIVER WATERS

The chemical quality of the water of creeks and rivers changes somewhat in the course of the flow from source to mouth. Small streams are the most affected by local conditions. A large river is the average of all its tributaries and, as a rule, the composition of the large rivers the more nearly resemble one another. The water of rivers consists of ground water plus rain, and contains as already stated a variable amount of suspended matter washed from the land and of dissolved solids due to contamination by sewage and refuse from towns and factories.

The waters from creeks and rivers in the state range from 28 parts per million of mineral matter in Morrison creek in eastern Jackson county, and 43 parts per million in the Wisconsin river at Tomahawk, Lincoln county, to 395 parts per million in the Root river at Racine.

The high mineralization of 500 to over 1,000 parts per million in the water of the Menomonie River at Milwaukee, and of some streams in other cities and villages is obviously due to pollution from sewage or manufacturing plants.

The average mineral content of creek and river waters from various parts of the state, as determined from about 85 analyses of probably nearly pure waters, is about 150 parts per million. The maximum range in mineral content of unpolluted creek and river waters, is probably between 25 parts per million in the northern part of the state to 350 parts per million in some of the small rivers in the eastern part.

The mineral content of the water of the Mississippi river at La Crosse is 142 parts per million, of the Chippewa river at Eau Claire 90 parts per million, of the Wisconsin river at Portage 98 parts per million, and of the Rock river at Watertown Jct. 241 parts per million. The analyses of the river waters are given in tables under the county description, but in order to show the general range in the composition of the river wa-

ters of the state, representative analyses of creek and river waters are also given in the following table:

TABLE 46.—*Mineral analyses of typical creek and river waters.*
(Parts per million.)

Creek or River.	Location.	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate $H_2(CO_3)_2$	Carbonate (CO_3)	Sulphate (SO_4)	Chlorine (Cl)	Nitrate (NO_3)	Organic and suspended matter.	Total dissolved solids.
Morrison Creek	Sec. 21, T. 21, R. 1, Jackson Co.	....	3.4	0.7	5.1	......	10.4	4.8	0.5	....	—	28
Creek	Near Cedar, Iron Co.	11.	8.	4.0	2.	......	23.	—	3.5	....	36.	54
Yellow river	Necedah	8	17.	7.	0.7	......	37.	4.1	2.3	....	......	72
Black river[1]	North La Crosse	....	16	7.	5.	......	38.	7.	5.	....	......	79
Chippewa river[2]	Eau Claire	12	13	4.7	8.1	48.	0	14.	1.1	....	3.	90
Wisconsin river[3]	Portage	13	14	7.	8.	58.	0	17	2.	.9	4.	98
Mississippi river[4]	La Crosse	10	29	9.	8	......	65	12	5	....	8	142
Fox river[5]	Menasha	....	32	17	11	......	94	9	5	....	......	168
Rock river[6]	Watertown Jct.	....	48	28	8	......	140	8	6	....	......	241
Sheboygan river	Sheboygan	10	37	26	6	......	93	35	20	....	13	282
Milwaukee river[7]	Milwaukee	5	44	24	6	......	115	20	8	....	22	225
Root river	Racine	10	74	38	18	......	169	75	8	....	......	395

[1] Average of 3 analyses.
[2] Average of 35 analyses.
[3] Average of 24 analyses.
[4] Average of 3 analyses.
[5] Average of 4 analyses.
[6] Average of 3 analyses.
[7] Average of 4 analyses.

It will be observed in the above table that the river waters of the north central part of the state are much less mineralized than the river waters of the eastern and southern part. There is also an appreciable increase in the proportion of sulphates as compared with carbonates in going from the northern part of the state towards the southeastern part.

The mineral content of river waters per volume is less in stages of high water than in stages of low water. This fact is well shown in the following tables[1] of mineral analyses of water from the Wisconsin river at Portage, table 47, and of the Chippewa river at Eau Claire, table 48.

[1] Quoted from U. S. Geol. Survey, W. S. P. No. 236, pp. 55 and 113.

TABLE 47. *Mineral analyses of water from Wisconsin River near Portage, Wis.*[a]

(Parts per million unless otherwise stated.)

Date (1906-7). From—	Date (1906-7). To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_3).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 11	Sept. 20	10	7.6	0.76	26	0.25	14	7.3	9.2	0.0	66	.....	1.3	0.8	117	5.2
Sept. 21	Sept. 30	15	9.6	.64	16	.40	14	7.2	9.2	.0	68	13	.9	2.5	109	5.3
Oct. 1	Oct. 11	10	4.0	.40	13	Tr.	16	8.5	7.3	.0	66	13	.5	1.5	105	4.8
Oct. 12	Oct. 22	5	5.6	1.12	15	.30	16	8.3	10	.0	75	16	.5	1.0	98	4.9
Oct. 23	Oct. 31	5	9.2	1.84	19	Tr.	16	8.9	7.6	.0	60	24	Tr.	4.0	108	6.5
Nov. 1	Nov. 10	5	5.6	1.12	17	Tr.	15	7.3	7.1	.0	51	15	Tr.	2.5	100	6.1
Nov. 11	Nov. 21	10	6.0	.60	6.6	.10	14	6.2	7.8	.0	49	11	.4	1.5	100	5.7
Nov. 22	Dec. 1	10	4.0	.40	6.4	.10	13	5.4	7.6	.0	48	14	.4	6.0	93	6.8
Dec. 2	Dec. 11	10	10	1.00	16	.30	.....	4.9	9.7	.0	43	19	1.3	1.3	89	6.8
Dec. 12	Dec. 22	10	5.6	.56	22	.40	13	2.4	11	.0	59	19	.4	3.2	112	6.5
Dec. 23	Jan. 1	5	2.0	.40	15	.40	14	6.8	.....	.0	48	25	Tr.	.9	105	.....
Jan. 2	Jan. 11	5	Tr.	.....	16	.40	15	7.6	7.8	.0	72	19	.4	1.8	106	.....
Jan. 12	Jan. 22	5	1.6	.32	15	.20	.....	7.2	7.3	.0	72	23	1.4	2.8	102	.....
Jan. 23	Feb. 1	5	Tr.	.....	13	.25	16	9.6	5.9	.0	71	.....	Tr.	1.8	105	.....
Feb. 2	Feb. 12	5	9.2	1.84	13	.40	18	6.7	13	.0	76	25	2.4	.....	108	.....
Feb. 13	Feb. 23	5	2.0	.40	13	.20	.....	7.6	10	.0	72	15	2.2	4.5	98	.....
Feb. 24	Mar. 6	5	Tr.	.....	11	.18	17	8.3	12	.0	75	23	1.6	2.1	109	.....
Mar. 7	Mar. 17	10	10	1.00	10	.23	15	.....	11	.0	73	.....	1.9	1.8	107	6.4
Mar. 18	Mar. 28	10	14	1.40	9.0	.20	11	7.2	5.1	.0	47	13	1.9	1.8	78	7.7
Mar. 29	Apr. 7	5	Tr.	.....	5.8	.20	9.2	2.8	4.3	.0	26	11	1.7	1.2	65	12.3
Apr. 8	Apr. 17	10	.....	.....	18	.15	11	4.8	.....	.0	49	21	1.0	.6	96	9.2
Apr. 18	Apr. 27	5	Tr.	.....	11	.20	10	4.9	5.9	.0	37	16	.5	1.9	78	7.8
Apr. 28	May 7	5	Tr.	.....	7.6	.25	11	5.0	5.7	.0	35	17	Tr.	.....	87	7.9
May 8	May 17	Tr	Tr.	.....	6.8	.20	.....	5.5	4.6	.0	43	11	Tr.	1.5	88	7.2
Mean		7	4.6	.86	13	.22	14	6.8	8.1	.0	58	17	.9	2.1	98	.....
Per ct. of anhydrous residue..		.....	.....	.....	14.3	c.3	15.4	7.5	8.9	31.5	.....	18.8	1.0	2.3	.....	.....

[a] Analysis September 11, 1906, to February 12, 1907, by W. H. Barr; February 13 to March 6, 1907, by H. S. Spaulding; March 7 to May 17, 1907, by Walton Van Winkle.

[b] Gaging station at Nocedah, Wis., 50 miles above.

[c] Fe_2O_3.

TABLE 48. *Mineral analyses of water from Chippewa River near Eau Claire, Wis.* [a]

(Parts per million, unless otherwise stated.

Date (1906-7) From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 14	Sept. 23	5	Tr.	.....	24	0.20	11	3.7	8.4	0.0	45	12	Tr.	3.2	111	6.4
Sept. 24	Oct. 3	10	Tr.	.....	11	.30	12	4.0	7.1	.0	44	9.0	1.8	2.1	98	6.1
Oct. 4	Oct. 13	5	Tr.	.....	5.8	.20	12	5.1	9.4	.0	45	14	Tr.	1.2	98	5.0
Oct. 14	Oct. 23	5	4.8	0.96	16	.15	13	6.3	7.0	.0	59	19	Tr.	1.3	103	4.9
Oct. 24	Nov. 2	5	9.6	1.92	15	.15	10	5.2	8.1	.0	39	16	Tr.	2.9	102	7.8
Nov. 3	Nov. 12	5	14.8	.96	12	Tr.	16	5.2	8.6	.0	41	13	Tr.	2.3	109	6.8
Nov. 13	Nov. 22	5	Tr.	.....	12	Tr.	12	4.2	.....	.0	33	14	Tr.	1.5	87	6.4
Nov. 23	Dec. 2	15	6.4	.43	16	Tr.	10	.....	7.5	.0	39	17	.0	.9	93	6.5
Dec. 3	Dec. 13	10	4.8	.48	17	.40	12	4.2	9.2	.0	40	19	.0	1.2	94	5.4
Dec. 14	Dec. 25	5	2.8	.56	15	.30	14	4.9	10	.0	53	17	.0	2.0	101	5.2
Dec. 26	Jan. 4	5	Tr.	.....	15	.25	14	5.7	7.3	.0	36	.....	.9	1.5	97	5.0
Jan. 5	Jan. 17	5	Tr.	.....	10	.25	16	5.3	.....	.0	58	13	Tr.	.....	94	4.9
Jan. 18	Jan. 27	10	6.4	.64	12	.40	15	5.8	13	.0	61	9.9	.2	2.7	96	.....
Jan. 28	Feb. 7	5	Tr.	.....	15	.25	17	4.8	5.6	.0	70	12	.8	.4	109	.....
Feb. 8	Feb. 18	5	4.0	.80	15	.15	17	8.5	11	.0	66	10	1.4	.6	97	.....
Feb. 19	Feb. 28	5	Tr.	.....	15	.25	17	4.1	8.7	.0	65	12	1.8	1.6	95	.....
Mar. 1	Mar. 10	5	Tr.	.....	18	.6	19	6.6	7.6	.0	68	15	1.2	1.5	104	.....
Mar. 11	Mar. 20	5	3.2	.64	12	.30	14	.....	9.1	.0	60	16	2.1	2.3	100	5.1
Mar. 21	Mar. 31	20	34	1.70	4.6	.37	.....	2.8	5.4	.0	25	15	1.2	1.5	59	11.2
Apr. 1	Apr. 10	10	10	1.00	6.8	.19	6.2	3.7	5.2	.0	.....	18	1.1	.4	58	11.2
Apr. 11	Apr. 20	5	7.6	1.52	6.8	.15	11	2.4	8.5	.0	22	14	.9	.1	72	7.9
Apr. 21	Apr. 30	Tr.	Tr.	.....	12	.18	9.8	3.7	4.6	.0	29	17	Tr.	.7	73	7.0
May 1	May 12	Tr.	Tr.	.....	9.6	.24	.....	5.2	4.4	.0	39	16	Tr.	Tr.	72	7.3
May 13	May 22	5	Tr.	.....	7.4	.18	8.2	2.3	.....	.0	28	11	Tr.	.1	63	8.7
May 23	June 1	5	Tr.	.....	7.0	.19	7.0	2.4	4.9	.0	28	9.9	Tr.	2.4	89	8.2
June 2	June 11	5	Tr.	.....	5.8	.16	10	3.0	4.3	.0	38	8.7	.8	Tr.	68	6.6
June 12	June 21	5	Tr.	.....	5.2	.25	10	4.3	5.9	.0	46	15	Tr.	.2	87	6.0
June 22	July 1	5	Tr.	.....	10	.18	15	.....	9.5	.0	56	14	1.2	.8	90	6.0
July 3	July 12	10	9.2	.92	9.8	.20	13	4.4	7.6	.0	45	15	1.0	.2	81	6.3
July 13	July 22	5	Tr.	.....	10	.30	14	.....	7.3	.0	.....	10	.5	.3	84	5.1
July 23	Aug. 2	7	Tr.	.....	12	.21	17	.....	.10	.0	59	9.9	Tr.	.3	93	4.8
Aug. 3	Aug. 13	5	Tr.	.....	14	.15	16	6.9	8.6	.0	61	.....	4.4	.3	90	.45
Aug. 14	Aug. 23	20	22	1.10	13	.19	16	.....	11	.0	55	12	Tr.	Tr.	94	.47
Aug. 24	Sept. 2	5	Tr.	.....	11	.09	13	5.2	13	.0	59	12	.4	.3	88	.44
Sept. 3	Sept. 12	5	Tr.	.....	14	.12	16	6.1	11	.0	72	15	.3	1.0	108	.42
Mean		7.0	3.7	.97	12	.22	13	4.7	8.1	.0	48	14	.6	1.1	90	.....
Per ct. of anhydrous residue		.....	.....	.....	15.5	[b].4	16.8	6.1	10.5	30.5	.....	18.0	.8	1.4	.....	.....

[a] Analyses September 14, 1906, to Feb. 7, 1907, by W. M. Barr; February 8 to February 28, 1907, by H. S. Spaulding; March 1 to September 12, 1907, by Walton Van Winkle.

[b] Fe_2O_3.

A fairly close similarity in the mineral content of the creeks and rivers and of the underground waters of the same localities may be observed on examination of the tables of analyses under the county descriptions. In general the surface waters are much less mineralized than the underground waters, the mineral content of the surface waters usually amounting to only 50 to 75 per cent of that of the underground waters in the same district.

In the average composition of the underground waters as shown by the districts of soft and hard waters (See Plate V), therefore, the usual mineral content of the creeks and rivers in these districts may be taken at 25 to 50 per cent less than the average given for the underground waters.

LAKE WATERS

The waters of lakes are similar to the waters of rivers in being lower in content of mineral matter than underground waters of the locality, and also are like the river waters in the constant and appreciable content of organic and suspended matter which they carry.

Inland Lakes.—The content of mineral matter in our inland lakes very generally is below that of the rivers that flow into them. The difference in some instances is only slight but in other instances the mineral content of the inland lakes is at least 35 per cent below that of rivers that flow into them. A similar difference is to be noted in the lower mineral content of the Great Lakes, as compared with that of their affluents.

The recent study of the inland lakes of Wisconsin by Birge and Juday[1] shows that the water of many of our lakes, those having proper depth and contour, become stratified during certain seasons of the year, "turn over" in the spring and autumn, and have in general an appreciable increase of mineral content with depth. These changes are directly due to the warming and cooling of the water through the warm and cool seasons of the year. These changes probably influence the living organisms in the lake and the bio-chemical reactions that are developed.

The mineral analyses of the water of 19 inland lakes of Wisconsin, samples taken at various depths, are shown in the following table:

[1] Inland Lakes of Wisconsin, Wis. Survey Bulletin No. XXII.

TABLE 49[1]—*Mineral analyses of water from inland lakes of Wisconsin.*
Analyses stated in parts per million.

Lake.	Date.	Depth: Meters.	Depth: Feet.	Silica (SiO_2).	Aluminum and Iron oxides ($Al_2O_3+Fe_2O_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).
Bass (Minocqua)....	Sept, 1907...	0	0	5.0	5.0	0.6	1.2	0.3	0.0	0.6	4.9	1.4	2.5
Beasley..............	Aug. 25, 1906	0	0	9.0	0.5	34.3	22.9	.....	.....	7.0	93	5.5	5.0
		14	46	26.0	1.1	47.0	23.4	.....	.....	0.0	111	3.4	3.4
	Sept. 9. 1907.	0	0	13.3	1.7	46.6	27.8	2.4	2.0	2.0	104	10.8	2.8
		8	26.3	21.6	0.8	43.5	27.8	2.2	2.1	0.0	118	9.4	2.5
		14	46	33.0	4.0	47.1	28.0	2.6	1.9	.....	121	11.8	2.0
	Aug. 3, 1908.	0	0	14.4	0.5	33.9	11.5	.....	.....	.....	.....	.....	....
		5	16.4	9.5	0.7	38.3	17.9	.....	.....	.....	.....	.....	....
		5.5	18.1	7.8	0.7	30.0	18.3	.....	.....	.....	.....	.....	....
		6	19.7	8.0	1.2	33.2	17.9	.....	.....	.....	.....	.....	....
		7	23	14.3	1.2	38.3	17.6	.....	.....	.....	.....	.....	....
		9	31.2	20.3	1.7	39.2	18.6	.....	.....	0.0	111	.....	....
		14	46	21.0	4.6	40.6	19.8	.....	.....	0.0	119	.....	....
Clear.................	Sept. 1907....	0	0	1.1	0.7	0.7	0.3	.....	.....	0.0	11	5.3	4.5
Devils................	Nov. 1908...	0	0	2.2	0.7	3.2	1.1	.....	.....	0.0	8.4	8.1	8.2
Elkhart..............	Sept. 12, 1907	0	0	6.9	0.8	16.2	19.5	3.8	2.4	8.0	107	10.7	6.0
		10	32.9	8.5	1.1	19.1	24.8	3.9	1.9	4.0	121	12.7	5.0
		21	68.9	9.4	1.8	24.1	26.8	4.3	2.2	0.0	129	10.6	5.2
		33	108.1	19.8	2.6	24.9	26.0	4.5	2.4	0.0	136	12.4	6.5
Garvin...............	Sept. 5, 1907	0	0	6.1	1.5	16.9	9.0	3.6	0.8	11.0	88	12.8	6.0
		6	19.7	7.6	1.8	23.0	23.0	.....	.....	0.0	117	11.4	5.0
		9	29.5	16.9	9.1	28.4	25.1	2.0	1.4	.....	153	11.5	5.6
Geneva...............	Sept. 26, 1907	0	0	7.8	0.7	18.3	25.8	4.6	2.5	11.0	94	12.5	5.0
		15	49.2	.....	0.7	20.0	27.0	4.4	2.5	0.0	111	13.0	5.0
		30	98.4	.....	1.1	21.8	27.3	4.1	2.2	0.0	113	.....	5.0
		41	134.5	11.1	2.0	22.8	27.5	4.2	2.8	0.0	114	14.1	3.5
Green................	Sept. 14, 1907	0	0	8.4	1.6	16.4	25.9	3.0	3.1	8.0	87	16.0	6.0
		15	49.2	8.4	2.0	23.8	26.0	3.5	2.8	0.0	109	15.8	5.5
		40	131.1	10.3	2.1	24.0	.....	3.4	2.9	0.0	110	16.3	6.2
		65	213.5	10.4	2.2	21.7	25.3	3.6	3.1	0.0	112	18.6	5.5
Kawaguesaga........	Aug. 26, 1907	0	0	14.2	1.6	6.9	2.2	2.6	1.7	0.0	29	7.9	2.7
		15	49.2	18.9	10.8	7.6	3.4	.....	.....	0.0	45	.....	....
Knights..............	Aug. 27, 1909	3	9.9	14.9	1.7	39.1	24.1	.....	.....	.....	.....	3.7	2.3
		4	13.1	14.3	1.1	32.5	22.7	.....	.....	.....	.....	4.0	2.5
		4	14.8	13.6	0.7	29.3	22.7	.....	.....	.....	.....	4.1	2.3
		5	16.4	18.6	1.4	38.8	23.8	.....	.....	.....	.....	3.4	1.9
Long (Waupaca)....	Sept. 9, 1907	0	0	14.9	1.0	30.4	17.1	2.9	3.3	2.0	111	8.6	2.5
		22	72.2	21.5	3.9	33.3	18.3	3.0	3.0	0.0	120	12.2	2.5
Mendota..............	Sept. 14, 1906	0	0	1.3	0.4	22.4	24.2	.....	.....	.....	.....	.....	....
		13	42.6	3.2	1.2	27.1	26.6	.....	.....	.....	.....	.....	....
		22	92.2	4.7	2.0	29.1	25.8	.....	.....	.....	.....	.....	....
	Jan. 15, 1907	0	0	0.8	1.4	27.4	21.3	.....	.....	.....	.....	.....	....
	May 3, 1907	0	0	1.2	0.8	28.5	25.5	.....	.....	5.0	89	12.2	3.0
	Sept. 18, 1907	0	0	9.2	1.6	17.4	21.8	2.7	2.6	10.0	74	15.2	3.0
		14	46	8.5	1.6	17.6	20.0	.....	.....	0.0	108	15.4	....
		17	55.8	9.0	1.8	17.6	20.2	.....	.....	0.0	116	15.7	3.0
		22	72.2	21.2	2.8	22.2	21.5	4.6	1.8	0.0	132	15.1	3.0
	Mar. 7, 1908	17	55.8	6.5	1.2	22.6	23.7	.....	.....	0.0	112	17.8	3.0
	Apr. 10, 1910	0	0	3.5	1.4	28.8	21.1	.....	.....	.....	.....	.....	....
	July 4, 1910	0	0	4.0	1.5	19.0	22.2	.....	.....	.....	.....	3.6	....

[1] Quoted from Wis. Survey Bulletin, No. XXII, pp. 170–1.

TABLE 49—*Mineral analyses of water from inland lakes of Wisconsin*—Continued.
Analyses stated in parts per million.

Lake.	Date.	Depth. Meters.	Depth. Feet.	Silica (SiO_2).	Aluminum and Iron oxides ($Al_2O_3+FeO_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).
North—East part....	Sept. 4, 1907	0	0	13.6	1.2	34.1	24.2	.....	.....	8.0	126	16.0	10.0
		22	72.2	14.3	2.6	41.6	24.8	.....	.....	0.0	139	18.7	5.0
North—West part....	Aug. 10, 1906	0	0	2.5	0.5	31.3	30.0	.....	.....	8.0	99	12.5	3.0
		6	21.3	2.6	.....	46.2	32.0	.....	.....	.....	.....	.....	.....
		8	26.2	9.1	0.8	49.1	27.5	.....	.....	0.0	131	14.4	2.5
		15	49.2	9.7	1.1	49.2	26.4	.....	.....	.....	127	12.1	4.0
		22	72.2	11.5	.....	49.3	27.4	.....	.....	.....	128	10.2	2.5
	May 10, 1907	0	0	3.0	0.6	47.3	28.0	.....	.....	12.0	114	13.4	4.0
	Sept. 4, 1907	0	0	11.4	0.7	32.9	25.1	2.4	1.2	11.0	115	18.4	9.0
		22	72.2	20.7	2.7	43.7	25.9	2.0	1.2	0.0	151	13.9	4.5
	Sept. 1, 1909	0	0	10.2	1.8	34.9	28.3	3.4	1.7	.....	.....	13.4	5.7
		22	72.2	22.0	2.2	49.6	32.7	6.2	3.0	.....	.....	9.2	2.7
Okauchee............	Sept. 5, 1907	27	88.6	17.6	1.5	34.3	25.9	3.2	1.4	0.0	66	13.9	4.0
Owen................	Aug. 20, 1908	0	0	8.8	0.8	12.0	4.0	.....	.....	1.0	33	0.0	1.5
		11	36.1	8.9	.....	15.6	3.3	.....	.....	0.0	34	0.0	2.0
		26	85.3	12.0	4.5	14.5	3.6	.....	.....	0.0	34	0.0	2.3
Pike.................	Aug. 25, 1908	0	0	10.9	1.2	14.9	3.9	.....	.....	0.0	34	0.0	0.5
		8	26.3	8.5	1.1	15.1	3.9	.....	.....	0.0	34	0.0	0.5
		10	32.9	12.5	2.5	14.8	4.4	.....	.....	0.0	34	0.0	0.5
		14	46	15.0	11.2	16.3	4.2	.....	.....	0.0	38	0.0	0.5
Rainbow.............	Sept. 10, 1907	0	0	12.0	1.4	15.6	14.6	2.2	3.3	8.0	90	8.6	4.5
		27	88.6	26.9	3.0	28.8	17.4	2.5	3.4	0.0	120	9.1	4.0
Trout (South Part.)	Aug. 19, 1907	0	0	13.0	1.1	6.7	2.5	0.8	0.3	0.0	28	6.4	3.0
Two Sister...........	Aug. 27, 1907	19	62.4	22.9	8.5	4.5	2.2	4.5	4.5	0.0	23	8.2	5.6

It will be observed on examination of the above table of analyses that there is very generally a notable increase with the depth in the content of all the constituents, the increase of silica and calcium being especially marked. In several of the lakes, the content of magnesia is nearly equal to or greater than that of calcium, as shown in the analyses of the water of lakes Elkhart, Geneva, Green and Mendota. Since the analyses of the underground waters in the localities of these lakes, as well as the analyses of the creek and river waters of the state, show a very general and fairly constant proportion of calcium to magnesium of about 2 to 1, there is very clearly a loss of calcium in the water of all those lakes that show equal amounts of these constituents. The loss of calcium is very obviously due to organisms in the lake that utilize carbonic acid and calcium in their biological processes. That calcium carbonate is precipita-

ted on the bottom of Lake Mendota is shown by analyses[1] of the mud obtained from the bottom of this lake. The analyses of incrustations on the leaves of *Potamogeton* and the stems of *Chara,* which thrive in our inland lakes and after death sink to the lake bottoms, consist very largely of calcium carbonate, $CaCO_3$, which has been abstracted from the lake waters by these organisms. The well known occurence of marl deposits in the bottoms of many of our hard water lakes and also in marshes that were lakes in relatively recent geological time, show conclusively the important effects of precipitation of calcium carbonate through the bio-chemical changes brought about in our lakes, by the work of organisms.

The utilization of silica by the silicious diatoms and the precipitation of iron oxide by such bacteria as *crenothrix* constantly take place in the lake waters, as these organisms are very generally present in the lake waters in large numbers.

Hence, on account of bio-chemical changes wrought in the lakes, thre is a constant loss of certain constituents which result in a gradual softening of the lake waters. It is only within lakes of certain depths, generally over 30 or 40 feet in depth, in the basin of which the water can remain for very long periods, that appreciable loss in the mineral constituents can be developed. In shallow lakes that are usually thoroughly drained by the rivers that flow through them, no appreciable changes are likely to be affected. Such shallow inland lakes as lakes Winnebago, Poygan and Puckaway are of this class. On the other hand the water of deep lakes such as Green, Elkhart, Geneva and Mendota, from the bottoms of which there is little or no outflow, show important changes in mineral content as compared with that of their affluents.

The mineral content of some 37 inland lakes cited in this report range from 16.4 parts per million in the small lake at Woodruff, Vilas County, to 298 parts per million in the small lake, Paul's Lake near St. Cloud, in Fond du Lac County. The analyses of the 37 lakes show an average mineral content of 141 parts per million. Complete analyses of the various lakes are given under the county descriptions.

In the following table analyses of representative lakes from various parts of the state are given to illustrate the general range in the composition.

[1] Wisconsin Survey Bull. 22, p. 171.

TABLE 50.—*Mineral analyses of water of typical inland lakes.*
Analyses stated in parts per million.

Lake.	County.	Silica (SiO_2.)	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na + K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4.)	Chlorine (Cl).	Organic.	Total dissolved solids.
Lake at Woodruff	Vilas	4.1	2.4	0.6	1.2	3.3	2.9	1.8	10	16.4
Lake near Worden	Oneida	4.	8.	0.8	4.7	4.7	24.9	......	11	48.
Summit	Langlade	5.6	11.3	3.8	8.1	14.	19.	4.8	12	63.
Long	Florence	8.	18.1	8.8	5.	49.	2.	7.7	20	99.
Lake near Oxford	Marquette	4.	24.	12.8	7.	65.	3.4	10.6	......	128.
Lake at Gillette	Oconto	6.	28.	19.	0.9	89.	......	1.4	28	145.
Winnebago	Winnebago	6.9	35.	20.	8.7	101.	13.9	5.3	8	190.
Elkhart	Sheboygan	......	31.	31.	2.9	117.	6.3	6.1	......	195.
Geneva	Walworth	3.6	29.	30.	8.5	115.	11.4	8.8	......	207.
Random	Sheboygan	2.4	41.	34.	3.3	140.	11.5	5.	......	239.
Cravath	Walworth	......	39.	36.	14.8	160.	7.5	2.4	......	261.
Paul's	Fond du Lac.	1.7	61.	35.	4.2	169.	17.9	6.7	60	298.

In the central and northern parts of the state in the region of the granite rock and thin sandstone where the groundwater is shallow the lake waters are very generally soft as illustrated by the lakes in Vilas, Oneida, Langlade and Florence counties. In other parts of the state where the groundwater is deep, the lake waters are hard or very hard, as illustrated by the lakes cited from Oconto, Winnebago, Fond du Lac, Sheboygan and Walworth counties. The water of Lake Winnebago which lies in a shallow basin is essentially the same as that of the Fox River. The mineral content of the water of Elkhart and Geneva, the analyses of each showing an excess of magnesium over calcium, is typical of the deep, hard-water lakes. The relatively high mineral content of Paul's Lake is probably typical for small hard water lakes that draw their principal supply from springs.

Great Lakes.—The waters of Lake Superior and Michigan are low in mineral content and for this reason are excellent for most industrial purposes. The mineral analyses[1] of water from Lake Superior, Table 51 samples taken at monthly intervals during the year, are shown in the following table:

[1] R. B. Dole, U. S. Geol. Sur. Water Supply Paper, No. 236, p. 101.

TABLE 51. *Mineral analyses of water from Lake Superior at Sault Ste. Marie, Mich.*[1]

[Parts per million, unless otherwise stated.]

Date (1906-7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[2]
Sept. 22....	2	......	11	0.09	13	3.2	3.9	0.0	59	4.1	0.25	1.0	63	602.95
Oct. 22....	1	......	8.7	.03	13	3.1	3.5	.0	56	3.8	.25	1.2	61	602.84
Nov. 22....	2	......	5.9	.04	13	2.9	2.0	.0	54	1.8	.45	1.4	54	602.66
Dec. 20....	Tr.	......	7.2	.08	13	2.9	3.6	.0	55	1.8	.30	1.3	58	602.45
Jan. 22....	Tr.	......	4.7	.03	13	2.9	2.0	.0	55	1.6	.45	1.2	53	602.22
Mar. 22....	3	......	12	.04	13	3.2	5.1	.0	55	1.7	.35	1.1	68	602.06
Apr. 20....	1	......	12	.11	13	3.1	3.5	.0	56	1.5	.30	1.0	64	601.94
May 23....	3	......	4.8	.09	13	3.0	3.0	.0	52	1.5	.55	1.0	57	602.10
June 22....	3	......	4.6	.04	14	3.2	3.3	.0	59	1.7	1.2	1.2	59	602.55
July 22....	2	......	5.7	.05	12	3.0	2.8	.0	58	1.5	1.2	1.0	55	602.70
Aug. 22....	5	......	5.3	.05	13	3.1	2.9	.0	60	1.6	.50	1.1	66	602.93
Mean....	2	Tr.	7.4	.06	13	3.1	3.2	.0	56	2.1	.5	1.1	60	......
Per ct. of anhydr's residue..	......	......	12.7	[3].2	22.4	5.3	5.5	47.5	......	3.6	.9	1.9	......	......

[1] Analyses by R. B. Dole and M. G. Roberts. U. S. Geol. Survey W. S. P. 236, p. 101.
[2] Gaging station at Marquette, Mich., 160 miles west.
[3] Fe_2O_3.

The samples of Lake Superior water were taken from St. Mary's river just above the locks at Sault Ste. Marie, Michigan. The mean total mineral content is 60 parts per million, the individual samples ranging from 53 to 66 parts per million.

The analyses of the Lake Superior water in Chequamegon Bay at Ashland show a somewhat higher mineral content than those in the above table from St. Mary's river. The average of total solids in 14 analyses[1] of samples taken from the surface and bottom of Chequamegon Bay is 67 parts per million, the range being from 58 to 74 parts per million. The analysis of Lake Superior water quoted as No. 1 in the table, p. 233, which is apparantly of unpolluted water, shows total mineral content of 65 parts per million. The water taken at various depths in Chequamegon Bay is, therefore, appreciably higher in mineral content than that of samples taken by the U. S. Geol. Survey from the St. Mary's river.

The mineralization of the water of Lake Michigan is about twice as strong as that of Lake Superior. Analyses made by R. B. Dole, U. S. Geol. Survey[2] of Lake Michigan water, Table 52, samples collected from

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[1] Analyses made in 1914 by the State Hygienic Laboratory in investigating Ashland City Water supply.
[2] W. S. P. No. 236, p. 73.

a ferry boat in the Straits of Mackinac at St. Ignace are shown in the following table:

TABLE 52—*Mineral analyses of water from Lake Michigan at St. Ignace, Mich.*[1]

[Parts per million, unless otherwise stated.]

Date (1906-7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[2]
Sept. 20......	1	....	17	0.02	27	7.7	4.9	5.9	109	6.6	0.20	2.6	126	581.08
Oct. 20.......	1	....	9.2	.02	26	7.4	4.4	6.6	103	6.5	.30	2.6	115	580.85
Nov. 20......	Tr.	....	9.5	.05	28	8.8	3.4	2.4	117	6.4	.35	2.9	120	580.72
Dec. 20......	1	....	10	.06	25	7.1	4.7	1.6	104	6.2	Tr.	2.6	108	580.67
Jan. 20......	1	....	6.2	.04	26	8.1	3.2	1.6	110	6.2	.4	2.8	110	580.62
Feb. 19......	....	....	12	.03	26	8.4	5.4	3.4	113	7.6	.35	2.8	120	580.64
Mar. 20......	....	....	14	.03	25	7.9	5.0	Tr.	111	7.9	.4	2.6	117	580.67
Apr. 21......	....	....	8.4	.04	26	8.1	4.7	.0	112	9.5	.3	2.4	115	580.83
May 20......	....	....	9.5	.03	27	8.7	5.4	2.6	115	7.8	.25	2.5	121	581.07
June 20......	....	....	8.6	.04	26	8.4	6.6	4.5	116	7.7	.55	3.0	120	581.42
Aug. 20......	....	....	11	.04	28	9.4	4.2	3.5	120	7.4	.4	3.2	123	581.51
Mean	Tr.	Tr.	10	.04	26	8.2	4.7	2.9	112	7.2	0.3	2.7	118	....
Per ct. of anhydrous residue. ..	....	....	8.5	[3].0	22.2	7.0	4.0	49.6	......	6.1	0.3	2.3	......	....

[1] Analyses by R. B. Dole and M. G. Roberts. U. S. Geol. Survey, W. S. P. 236 p. 73.
[2] Gaging station at Mackinaw, Mich., 5 miles away.
[3] Fe_2O_3

The 11 analyses of samples shown in the above table range from 108 to 126 parts per million of total dissolved solids, the mean of the total dissolved solids being 118 parts per million. Quite invariably, however, the analyses of Lake Michigan water of samples taken adjacent to the lake shore, in eastern Wisconsin, show an appreciably higher mineral content than that indicated in the above table. The analyses of Lake Michigan water are given under the county descriptions, but for purposes of comparison with those of the above table are compiled in the following table:

TABLE 53.—*Mineral analyses of water of Lake Michigan at various localities.*
(Parts per Million.)

Locality.	Probable Depth.	Silica (SiO_2)	Aluminum and iron oxide ($Al_2O_3+Fe_2O_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Carbonate radicle (CO_3)	Sulphate radicle (SO_3)	Chlorine (Cl)	Nitrate (NO_3)	Organic matter.	Total dissolved solids.	Analysts.
	Feet.												
Port Washington..........	18-30	5.6	2.4	30.8	9.2	5.7	66.	9.	4 7	....	....	134	C. & N. W. Ry. Co., Nov. 1907.
Milwaukee	......	16.	......	34.	10.2	1.5	72.	6.	3.	....	....	142	G. Bode. Before 1877.
	50	6.6	1.6	33.9	11.8	2.2	66.	21.6	3.5	....	tr.	148	Dearborn D. & C. Co., Mar. 1912.
	50	5 6	1.9	26.6	11.3	6.1	68.	8 0	3 5	....	1.	131	Dearborn D. & C. Co., Sept. 1907.
	......	....	1.5	31.6	10.5	3.4	70.	6.9	2.9	....	....	127	C. M. & St. P. Ry. Co. July 1889.
	......	....	4.5	34.0	11.2	4.8	76.	8.1	3.1	....	....	142	C. M. & St. P. Ry. Co. Dec. 1894.
	50	....	......	31.8	10.6	6.7	71.	9.0	7.2	....	....	136	C. M. & St. P. Ry. Co. Aug. 1907.
Racine.........	47	2.1	1.2	30.7	10.7	5.6	66.	12 2	7.	....	tr.	135	Dearborn D. & C. Co. Feb. 1892.
Kenosha.......	34	5.4	1.8	32.9	10.6	5.2	68	15 1	5.3	....	6.	145	Dearborn D. & C. Co. Dec. 1911.
Chicago........	30-50?	5.1	.3	32.1	10.9	3.1	73.	6.8	2 3	....	....	134	J. H. Long Ill. State Board of Health.

The mineral analyses of Lake Michigan water in Table 53 are appreciably higher in mineral constituents than those of Table 52. The higher mineral content of the lake water at the south end of the lake as compared with that near the outlet in the Straits of Mackinac, has been suggested[1] as possibly due to the higher mineral content of the streams that enter the southern end of the Lake, as compared with those of the northern end, and also[2] as possibly due to currents from Lake Huron, bringing into the Straits of Mackinac the less mineralized water of Lake Huron. While both of the explanations may be applicable to a certain extent, the writer is of the opinion that the depth at which the samples were taken is a controlling factor and should be considered, in any study of the composition of the lake water. It has already been pointed out, and it is clearly shown in the analyses of the water of the inland lakes (Table 49), that there is a tendency for the lake waters to become stratified there being a fairly constant increase in the mineralization of the water in approaching the bottom of the lakes. It seems

[1]State Water Survey of Illinois, Bull. 8, p. 35.

[2]R. B. Dole, Waters of the Great Lakes, Jour. of N. Eng. W. W. Ass'n. Vol. 23, p. 259.

reasonable to believe that a somewhat similar increase in mineralization with depth is also true for the waters of the Great Lakes. Most, if not all the waters analysed for city supplies, in the above table, 53, are from the bottom of the lake, at depths ranging from 30 to 50 feet, while those analyzed from the Straits of Mackinac are from the surface of the lake. The difference in degree of mineralization shown at the north and the south ends of the lake may be entirely due, therefore, to the difference in source of the various samples analyzed, relative to depth, to the surface, and to bottom of the lake.

In the same manner may be explainable the lower mineral content of the water of Lake Superior taken at the outlet, from the surface of St. Mary's river, as compared with the higher mineralization of the water taken from the bottom of the Chequamegon Bay at a depth of 26 feet at Ashland, referred to on p. 219.

PART II

THE DESCRIPTION OF LOCAL WATER SUPPLIES BY COUNTIES

Under Part II the description of the local water supplies of each county is given separately, under the following headings:

Surface features
Geological formations
Water-bearing horizons
Flowing wells
Springs
Water supplies for cities and villages
Quality of the water
    Mineral analyses of the water supplies

Adams County

Adams County, located in the central part of the state, has an area of 682 square miles and a population of 8,604. About 70.3 per cent[1] of the county is in farms, of which 46.2 per cent is under cultivation.

SURFACE FEATURES

The surface of Adams County is mainly a broad valley bottom plain. Into this plain, the Wisconsin River, along the western boundary, has entrenched itself to a depth of about 150 feet, while the short tributary

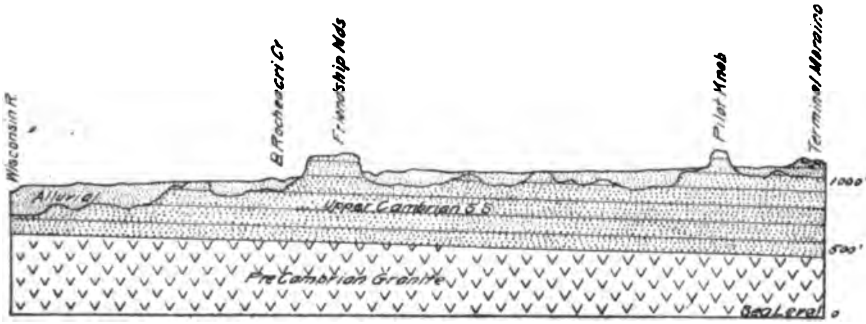

Fig. 18.—Geologic section, east-west, across central Adams county.

streams in the western part of the county have cut down to grade with the Wisconsin. The abrupt sandstone mounds and castle rocks are striking scenic features and generally rise from 100 to 250 feet above the alluvial plain. The terminal moraine in the southeastern part is formed of glacial drift hills, which rise from 50 to 75 feet above the general level of the plain. The altitude along the Wisconsin River bottoms ranges from about 850 feet in the southern part of the county to 950 feet in the northern part. The altitude of the alluvial plain ranges from 1,000 feet in the southern part to 1,100 feet in the northern, while the sandstone mounds rising above this plain reach altitudes of something over 1,200 feet above the sea level.

GEOLOGICAL FORMATIONS

The geological formations of the county are the Upper Cambrian "Potsdam" sandstone, the glacial drift, and the sandy alluvial forma-

[1] The per cent of land in farms and of land under cultivation in each of the counties is taken from the U. S. Census for 1910, Vol. VII., pp. 916–920.

tion. The sandstone is the bed rock formation of the entire county and projects up through the overlying alluvial sand and the glacial drift. The alluvial sands and loams form the level plains. The glacial drift forms a belt of terminal moraine of irregular hills and basins, associated with swamps and lakes, crossing the southeastern part of the county. The geological structure is illustrated in Figure 18.

The thickness of the surface formation varies greatly, and probably reaches a maximum of 250 to 300 feet in the valleys. The thickness of the sandstone also varies greatly on account of the extensive erosion of this formation. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Adams County.

Formation.	Thickness, Feet.
Surface formations	0 to 300
Upper Cambrian (Potsdam) sandstone	0 to 600
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing horizons are the sandstone and the alluvial sand formation. The drift is an important source of supply only in the southeastern part. The wells are quite generally of shallow depth, varying from 20 to 40 feet in the sand. In the vicinity of Arkdale and White Creek, wells are generally 30 to 40 feet to water level. On Dell Prairie, north of Kilbourn, many of the wells, however, reach a depth of 150 to 160 feet to obtain water.

WATER SUPPLIES FOR CITIES AND VILLAGES

Friendship.—Friendship, the principal village, and the county seat, has a population of about 500. It is located on the alluvial plain, and the water supply is derived from wells mainly driven into the sand to a depth of about 40 feet.

QUALITY OF WATER SUPPLIES

Only four mineral analyses of water of Adams County are available, as shown in the table. The water is usually soft and may be considered typical for waters whose source is in the surface sand, or in the sand-

stone formation in this section of the state. In the southeastern part of the county, waters from the glacial drift are likely to contain a larger amount of mineral matter than waters from the alluvial sand, on account of the presence of much limestone in the drift.

The wells are likely to be of shallow depth over considerable portions of Adams County, and hence, proper caution regarding the contamination of the well supplies should be observed. Open wells, less than 20 or 25 feet in depth, should be avoided. The best type of well is the driven or drilled well, properly cased down to a depth of at least 25 or 30 feet and preferably 40 or 50 feet.

The water from the wells near Friendship, in alluvial sand, contain only 0.54 and 0.58 pounds of incrusting solids in 1,000 gallons while those in sandstone contain 0.83 and 1.41 pounds in 1,000 gallons.

Mineral analyses of water in Adams County.

(Analyses in parts per million.)

	Surface deposits.		Upper Cambrian (Potsdam) sandstone.	
	1.	2.	3.	4.
Depth of well.....feet..	48	24	305	320
Silica (SiO_2)	8.7	9.9	9.1	7.0
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	1.0	0.5	1.5
Calcium (Ca)	14.6	12.7	35.5	38.1
Magnesium (Mg)	6.3	5.9	0.4	18.8
Sodium and potassium (Na+K)	0.2	0.9	13.0	2.8
Carbonate radicle (CO_3)	37.3	30.3	66.5	103.4
Sulphate radicle (SO_4)	2.9	5.5	4.2	2.2
Chlorine (Cl)	3.1	0.1	2.8	2.8
Total dissolved solids	73.	66.	132.	177.

1. Well on Bidar's farm, Friendship. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Feb. 23, 1911.
2. R. R. contractor's well near Friendship. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Sept. 16, 1910.
3. Railroad Well No. 2, Friendship. Analyst, G. M. Davidson, C. & N. W. Ry. Co., May 10, 1912.
4. Railroad well No. 1, Friendship. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Aug. 30, 1911.

Ashland County

Ashland County has an area of 930 square miles and a population, in 1910, of 21,965. About 10.5 per cent of the county is in farms, of which 33.6 per cent is under cultivation. Ashland, the principal city, has a population of 11,594.

SURFACE FEATURES

The divide between the Lake Superior and Mississippi drainage, extending across the southern part of the county, reaches an elevation of over 1,000 feet above the level of Lake Superior, about 1,600 feet above sea level. The slope is relatively steep northward towards the lake in the northern part; the central part is broken by a prominent, broad ridge of the Penokee Range, and the southern part is very gently sloping towards the south. Marshes and lakes are a common feature in the central and southern part.

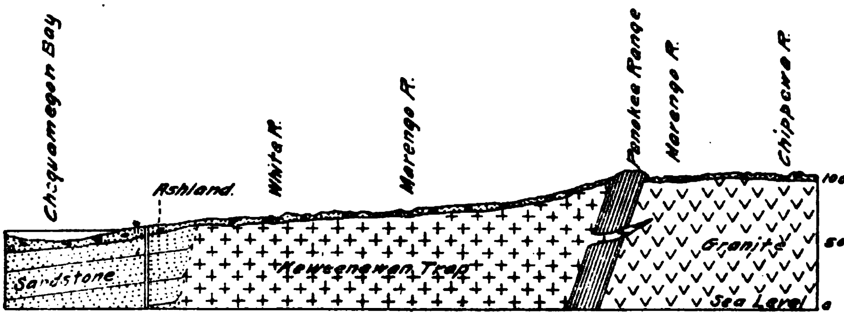

Fig. 19.—Geologic section north-south, along the boundary of Ashland and Bayfield counties.

GEOLOGICAL FORMATION

The rock formations are the Lake Superior sandstone extending about 10 to 25 miles south of the lake, south of which lies a narrow belt or ridge of the Keweenawan trap, and south of the trap ridge is the Huronian formation of granite and metamorphic rocks. The indurated rock formations are quite generally covered with surface deposits of glacial drift, red clays and stratified sands.

The maximum thickness of the Lake Superior red sandstone is very great, apparently 15,000 to 20,000 feet. This formation consists of much fine-grained material and only a small portion of coarse sand and

grit. Shale beds are common throughout the formation. The surface deposits of drift and associated red clays and stratified sands probably reaches a maximum thickness of 400 to 500 feet in old filled valleys adjacent to the lake. Farther south the drift is very thin or absent in many places. The geological structure is illustrated in figure 19.

The approximate range in thickness of the formations in Ashland County may be summarized as follows:

Thickness of formations in Ashland County.

Formation.	Thickness, Feet.
Surface formations	0–600
Lake Superior sandstone	0—20,000
Keweenawan Trap and the Archean Granite	....

WATER-BEARING HORIZONS

The principal water-bearing formations are the surface deposits of glacial and stratified sands. A common source of water supply is the sandstone formation although the Lake Superior red sandstone is much less efficient than the Upper Cambrian sandstone of southern Wisconsin as water-bearing strata. The trap rock and the granite formations also contain a small though usually sufficient amount of water for farm purposes. In the granitic formations the water is very generally only within the open fractures and joints of the rock.

The depth to water level is variable throughout the county being near the surface in valley bottoms and generally less than 50 or 100 feet from the surface on the uplands and in the drift hills.

An artesian slope of considerable importance lies along the south shore of the lake and is fully described under water supplies for the city of Ashland.

WATER SUPPLIES FOR CITIES AND VILLAGES

Ashland.—In the vicinity of Ashland conditions are very favorable for groundwater supplies, and likewise for some distance south of Ashland. Here, as at Superior, the red sandstone and the sand and gravel strata, from which the water is obtained, outcrop between the lake shore and the trap ridge farther south. Flowing wells are usually confined to the vicinity of the lake shore.

The water in the flowing wells at Ashland has risen 44 feet above the

level of Lake Superior, but observations showed that in most of the wells at the present time the water rises only from 15 to 20 feet above the lake, as at Superior. The water-bearing gravel seam generally does not lie as deep as at Superior, varying in depth from 90 to 170 feet. It shows considerable variation in thickness.

There are between 100 and 150 flowing wells in the city and immediate vicinity. Besides these flowing wells there is a large number of similar wells that must be pumped, where the land surface lies too high relative to the artesian water-bearing strata. From all of these wells the water is obtained from the sand and gravel strata lying between the sandstone rock and the overlying red clay. Some of the wells have ceased to flow during the last few years, and it is held by some that the supply is giving out, but the facts do not seem to support this view. No such decrease seems to be noticeable in other wells situated no less favorably, while in a number of cases it has clearly been shown that some of the wells stopped flowing because the screen or lower part of the pipes became clogged by sand or gravel. Upon removing this obstruction the wells flowed as vigorously as before. Clogging at the base of the wells seems to account for most of the discontinued flows, although other causes sometimes contribute to lessen the flows.

Where the impervious clay, capping the gravel seam, rises to higher elevations some distances away from the lake, flowing wells may be obtained in favorably situated places. This is illustrated by the occurrence of the flowing well on the farm of J. J. Dubuiska, about four miles west of Ashland, near Ashland Junction, Bayfield County, the well being located in a valley at least 25 feet above the lake level. On passing through the clay the well digger broke through into a fine flow of fresh, cool water, which rose several feet above the surface.

The city water supply is furnished by the Ashland Water Company, a portion of the supply being obtained from one large open well, 58 feet in diameter, 39 feet deep, and ten wells 6 inches in diameter, driven to depths ranging from 40 to 60 feet. These are located on the northeast side of Twelfth Avenue East and Water Street, about one mile northeast of the Ashland Post Office. The wells are put down on a plain, whose elevation is 608 feet above tide, or six feet above Lake Superior. The supply from the wells is usually only one-fifth of the water used by the Company, the remainder being pumped from Lake Superior and passed through filters. The lake supply is drawn through a 24 inch intake, 5,200 feet long, at a depth of 22 feet. The average daily pumpage is about 1,-277,000 gallons. The sewage is emptied, without treatment into the

lake. About 80 to 85 per cent of the houses are connected with the water system, and about 30 per cent have sewer connections.

The accompanying sanitary analyses of the well water, by E. G. Smith, May 25th, 1894, showed a large amount of total solids in the water as compared with the soft seepage water of Lake Superior pumped from the wells at Superior.

Sanitary analyses of water from wells of Ashland Water Co.

	Parts per million.
Volatile residue	256.5
Fixed residue	212.04
Total solids	468.54
Free ammonia	0.024
Albuminoid ammonia	0.006
Nitrites	None.
Nitrates	None.
Oxygen consumed, after 10 mins	0.3
" " " 60 "	0.4
" " " boiling 10 min.	0.8
Chlorine	94.5
Hardness (Clarke Scale)	Temporary.— 4°
"	Permanent.— 7°
"	Total —11°
Result after heating ressdue	No change in color.

Recently plans have been made and adopted for installing a new city supply, the water to be obtained from flowing springs located in the southwest part of the city.

At the works of the Ashland Iron & Steel Company[1] is the deepest well in Wisconsin, having a total depth of 3,095 feet. The water is used for cooling the condensers at the chemical plant, and is pumped by compressed air.

Section of well of the Ashland Iron & Steel Company.

Strata.	Thickness.	Diameter of well.
Pleistocene formation	Feet.	Inches.
Red clay	40	10
Hard pan with boulders	43	10
Red sand	92	10
Lake Superior sandstone		
Fine-grained red and white sandstone	825	8
Coarse, loosely cemented sandstone, chief water horizon	30	6
Red and white sandstone with thin shale beds	1,640	6
Red shale	425	6
Depth	3,095	

[1] At present, 1914, the Lake Superior Iron & Chemical Co.

This well is remarkable locally for its great depth, and because it furnishes a definite record of the great thickness of the Lake Superior sandstone formations, on the south shore of Lake Superior. Analyses of the water were made from three levels, namely: 1,435 feet, 2,000 feet, and 2,800 feet.

Mellen.—Mellen, having a population of 1,833, has a public water supply, recently installed, the supply being obtained from a large spring located 2 miles south of the city and 186 feet above the level of the main street. The water is carried from the spring in a 6-inch pipe, flowing into a stand-pipe built on a hill in the city. The rock formation at Mellen is the Keweenawan trap and Huronion slate overlain in places with glacial drift.

Glidden.—The population is estimated to be 1,000. A public water supply is installed, the source of the supply being the Chippewa river, one intake at depth of 6 feet, and one well 20 feet deep in surface gravel. The average daily pumpage is 15,000 gallons, and about 82 houses are connected with the supply. Private wells are usually 30 to 35 feet deep, drawing the water supply from gravel beds.

At Sanborn most of the water is obtained in wells at depths of from 90 to 150 feet without reaching rock. The water occurs in sand overlain by clay.

At Marengo, in the river valley, a flowing well 60 feet deep in drift, is reported. Throughout the La Pointe Indian Reservation wells at logging camps range from 100 to about 400 feet in depth, passing through clay and fine sand. At Birch a well 300 feet in depth passes through dry sand. At Odanah, a few feet above the lake level, flowing wells are obtained at a depth of about 150 feet.

QUALITY OF THE WATER.

The water of Lake Superior is soft water, showing a content of only 65 parts per million of mineral matter, as shown in analyses No. 1. The analyses No. 2 and No. 3 of the Ashland City Water Supply shows a certain amount of pollution, as indicated by the higher content of the chlorine and sulphate radicles and of organic matter, a condition certain to develop wherever the city sewage and refuse from mills is emptied into the source of the water supply.

As shown in the table, the relatively shallow wells in Ashland contain water of low or moderate mineral content, while the deep well of the Ashland Iron & Steel Company contains water highly mineralized and distinctly salty. The hard water of low or moderate mineral con-

tent is obtained from surface deposit wells or wells which penetrate only a short distance into the Lake Superior sandstone, while the salty water is obtained from wells that reach the deeper strata of the Lake Superior red sandstone.

The pure unpolluted water of Lake Superior, Analyses 1, contains 0.49 pounds of incrusting solids, in 1,000 gallons. The railroad shop well at Ashland, Analyses 7, contains 1.72 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Ashland County.

(Analyses in parts per million.)

	Lake Superior.				River.	Lake Superior red sandstone.					
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11.
Depth of well ......feet..	......	......	......	......	....	157	200	......	1,435	2,000	2,800
Silica (SiO_2)..............	2.9	4.8	3.6	4.	15.2	9.4	15.4	2.8	Trace	......	......
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	1.0	1.2	5.2	1.6	1.7	1.0	2.9	6.4	....	......	......
Calcium (Ca)............	18.1	20.2	19.6	14.1	24.1	24.6	34.3	53.3	148.6	82.0	119.5
Magnesium (Mg).........	2.9	5.9	3.9	4.4	12.2	8.7	27.7	31.7	80.9	24.7	34.5
Sodium and potassium (Na+K)................	2.2	13.8	9.2	11.1	1.6	32.0	32.2	34.6	180.0	197.0	165.8
Carbonate radicle (CO_3).	34.5	44.9	30.4	28.9	66.3	58.4	121.7	68.0	75.9	171.7	255.7
Sulphate radicle (SO_4)...	......	......	13.9	5.2	....	......	......	18.7	84.7	20.5	13.9
Chlorine (Cl).....	3.6	21.2	14.2	17.1	2.5	0.5	34.8	145.6	623.6	303.0	255.1
Organic matter..........	......	15.6	......	......	15.6	......	......	......	Trace	......	......
Total dissolved solids..	65.2	112.0	100.0	86.4	123.6	134.6	269.0	311.1	1,193.7	798.9	844.5

1. Chequamagon Bay, Lake Superior. Sample taken through ice. Analyst, G. M. Davidson, Dec. 1897.
2. Chequamagon Bay, Lake Superior, Ashland City water supply. Analyst, G. M. Davidson, Aug. 1902.
3. Chequamagon Bay, Lake Superior, Ashland City water supply. Analyst, Milwaukee Ind. Chem. Institute, Feb. 23, 1909.
4. City water, direct from mains, Ashland. Analyst, Dearborn Drug & Chemical Co., Sept. 13, 1905.
5. Water from junction of White and Bad rivers, at Odanah. Analyst, G. M. Davidson, Aug. 21, 1902.
6. Well at Railroad Shops, C. & N. W. Ry. Co., Ashland, ¼ mile N. E. Analyst, G. M. Davidson, Dec. 1897.
7. Well at Railroad Shops, C. & N. W. Ry. Co., Ashland. Analyst, G. M. Davidson, Nov. 1899.
8. Well at Ashland. Analyst, Milwaukee Ind. Chem. Institute, Feb. 23, 1909.
9. Well of Ashland Iron & Steel Co. well 3095 feet deep, sample taken at depth of 1435 feet. Analyst, Chemist, Ashland Iron & Steel Co.
10. Well of Ashland Iron & Steel Co., well 3095 feet deep, sample taken at depth of 2000 feet. Analyst, Chemist, Ashland Iron & Steel Co.
11. Well of Ashand Iron & Steel Co., well 3095 feet deep, sample taken at depth of 2800 feet. Analyst, Chemist, Ashland Iron & Steel Co.

Barron County.

Barron County located in the northwestern part of the state has an area of 878 square miles and a population of 29,114. About 72.6 per-cent of the county is laid out in farms of which 41.4 per cent is under cultivation.

SURFACE FEATURES.

The surface of Barron County varies from slightly undulating in the northern part where the drift deposits are abundant to hilly in the southern part where the drift is thin and the sandstone formation is deeply incised by the rivers and streams. A belt of low hilly terminal moraine extends across the northeastern and also the northwestern parts of the county. Quartzite ridges are prominent features east of Rice Lake and north of Canton and Lehigh. A broad valley bottom plain lies along the Red Cedar river in the vicinity of Rice Lake, Cameron and Chetek. A similar valley, but more narrow, is occupied by the Vermillion river at Barron and east of Cumberland and by the Hay river at Prairie Farm. The altitudes generally range from 1,000 to 1,200 feet along the valley bottoms, and 1,200 to 1,400 feet over the intervalley areas. The quartzite ridges east of Rice Lake reach a maximum altitude of over 1,600 feet. The soils in the bottom lands are generally sandy loams and silt loams, while those on the uplands are generally silt loams.

GEOLOGICAL FORMATIONS.

The geologic formations are the Barron quartzite, in the eastern part of the county, and the Upper Cambrian (Potsdam) sandstone over the remaining parts of the county. The Lower Magnesian limestone caps the upland ridges in the southwestern part. Glacial drift is an abundant formation over the bed rock in the eastern, northern and western parts of the county. Alluvial gravel and sand forms a broad plain along the Red Cedar river and its tributaries in the central and southern portions of the county.

The geological structure is illustrated in Fig. 20.

The thickness of the surface formations of glacial drift on the interstream areas, in the northern part, probably reaches a maximum of 150 to 200 feet, though the thickness is usually only 25 to 50 feet. The thickness of the alluvial sand and gravel in the valleys probably reaches 200

to 250 feet in the deepest parts of the old channels. The complete thickness of the Upper Cambrian (Potsdam) sandstone is preserved only

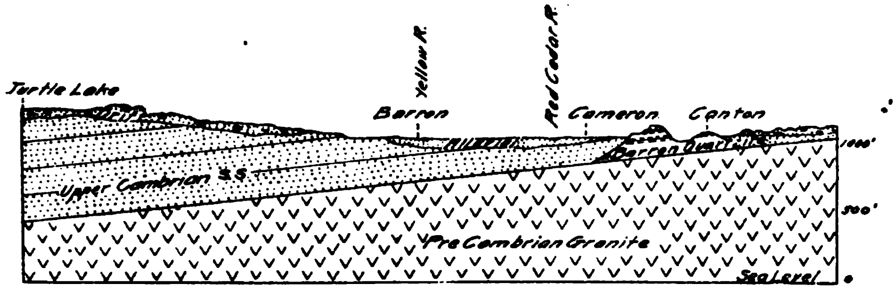

Fig. 20.—Geologic section, east-west, across central Barron County.

where overlain by the Lower Magnesian limestone in the southwestern part of the county. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Barron County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Lower Magnesium Limestone (only in southwestern part)	0 to 100
Upper Cambrian (Potsdam) sandstone	0 to 800
The Pre-Cambrian formations	....

PRINCIPAL WATER-BEARING HORIZONS.

The water-bearing horizons are the sandstone, the glacial drift, and the alluvial sands and gravels along the river. The wells are of variable depth from 10 to 30 feet in the valleys, up to 200 feet upon the upland ridges. Well records show a depth of drift of over 200 feet in places north of Barron and west of Rice Lake.

SPRINGS.

Springs are a common source of water suply in the valley bottoms of the southwestern part of the county. These springs are especially abundant along the Hay river and tributaries and are the source of an excellent water supply on many farms.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Rice Lake.—Rice Lake, located on Rice Lake, an expansion of Red Cedar river, has a population of 3,968. The city water supply is obtained

from a 6-inch well, 220 feet deep, 20 feet in sand and gravel, 200 feet in sandstone, striking hard rock, probably granite or the Barron quartzite formation, at bottom. The elevation of the surface at the well is 1,146 feet. The water level is about 15 feet below the surface. Private wells in the city are generally from 15 to 40 feet deep in the sand and gravel. No sewerage system is installed, though one is being contemplated.

Barron.—Barron, the county seat, situated on the Vermillion river, has a population of 1,449. The city water supply is obtained from a large open well, fed by springs, located on the bank of the river. No sewerage system is installed. About 25 per cent of the families are on the water supply system. Private wells generally vary in depth from 15 to 30 feet in sand and gravel.

Cumberland.—This city, population 1,445, is situated on Beaver Lake. The city water supply is obtained from a 6-inch well, about 615 feet deep, located near the lake. The capacity of the well is 360,000 gallons per day. About 60 per cent of the houses are connected with the water supply. Best information that could be obtained in regard to the formation passed through in the city well shows 179 feet of drift, and 436 feet of sandstone and soft clay or shale, most of the latter formation being soft red formation of shale of unusual character for the Potsdam formation. The private wells in the city vary from 20 to 125 feet in depth in gravelly and sandy drift. No sewerage system is installed.

Cameron.—This village, population about 562, is located on a sandy gravelly plain. A city supply system is installed, the water being obtained from a 4-inch well 85 feet deep. Private wells are generally from 30 to 45 feet in sand and gravel. The daily consumption of water from the city supply is about 100 barrels. About 75 per cent of the houses are reported to connect with the city system. No sewerage system is installed.

Chetek.—Chetek, situated on Lake Chetek, has a population of 829. It is located on a sandy alluvial plain. Most of the private wells are shallow, the wells being 10 to 30 feet in sand and gravel. The city supply is obtained from three 6-inch wells, 40 feet deep. About 20 per cent of the houses connect with the city water supply, the average daily pumpage being 5,000 gallons.

Turtle Lake.—This village, having a population of 442, is supplied with water from private wells in the drift and sandstone varying in depth from 30 to 150 feet. The deepest wells, only those more than 135 or 140 feet, reach the sandstone. The deep well water is hard water.

Prairie Farm.—On Hay Creek, population 368, is supplied with water from shallow wells, generally from 30 to 40 feet deep in sand and sandstone. Dallas, population 342, located on Pine Creek, is supplied with water from shallow wells, from 20 to 40 feet deep in sand.

QUALITY OF WATER SUPPLIES

Only one mineral analyses of the water of Barron County is available, that of the city supply at Cumberland. However, the water is probably of low mineral content for all parts of the county, except that portion of the southwestern part, where limestone is present. The water supplies obtained from shallow wells in the sand and gravel formation in the broad river valleys is likely to be soft while that obtained from the deep wells in the sandstone uplands is likely to be hard water.

Mineral analyses of water in Barron County.

(Analyses in parts per million.)

	Upper Cambrian (Potsdam) sandstone.
Depth of well .... feet	615
Silica (SiO_2)	20.2
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	2.6
Calcium (Ca)	33 9
Magnesium (Mg)	14 1
Sodium and potassium (Na + K)	2.7
Carbonate radicle (CO_3)	85 8
Sulphate radicle (SO_4)	....
Chlorine (Cl)	4 3
Organic matter	7.7
Total dissolved solids	164.

1. City Water Supply, Cumberland. Analyst, G. M. Davidson, Nov. 27, 1911.

Bayfield County

Bayfield County, bordering on Lake Superior, has an area of 1,497 square miles and a population of 15,987. Only 12.5 per cent of this county is in farms of which 18 per cent is under cultivation. Washburn, population 3,830, and Bayfield, about 2,500, are the principal cities.

SURFACE FEATURES

The land surface is quite gently sloping and rolling, with altitudes varying from 602 feet above sea level along the lake up to 1,300 and 1,400 feet in the northern part of the county along the Bayfield Ridge.

The Bayfield Ridge, so far as known, consists wholly of drift and the summit shows considerable areas of very rough sandy glacial moraine. The deep pits among the hummocky moraine hills are often over 150 feet deep. In the central and southeast part of the county is a broad sandy country known as the "Pine Barrens", in which small lakes are a common feature.

GEOLOGICAL FORMATIONS

The geological formations are the Pre-Cambrian granitic formations, the Keweenawan trap, the Lake Superior sandstone, the glacial drift and the lacustrine red clays. The northern part of the county is underlain with Superior red sandstone, over which is a thick mantle of clay and gravel, forming an artesian slope. and producing an excellent source of underground water supply. The southern part of the county is underlain with crystalline rock, over which is a variable thickness of glacial drift. The thickness of the formations may be summarized as follows:

Range in thickness of formations in Bayfield County.

Formation.	Thickness.
	Feet.
Surface formation	0 — 600
Lake Superior sandstone	0 — 15.000
Keweenawan Trap and Huronian granite	....

The section, Fig. 19, illustrates the general geological structure of Bayfield and Ashland counties.

WATER-BEARING HORIZONS

The principal water-bearing formations are the surface deposits of sand and gravel associated with the glacial drift and the red clays . The Lake Superior sandstone varies considerably in content of water. The coarse sandstone beds carry an abundant supply but the fine grained beds of shaly sandstone are poor aquifers. Usually, however, a considerable increase in the supply over that obtained in the drift can be obtained by drilling 20 to 40 feet into the underlying sandstone.

The Keweenawan trap rock and the Huronian granitic formations are impervious, the supply being confined to the open fractures and joints.

A well defined artesian slope is developed in the surface deposits of stratified clays and sands adjacent to Lake Superior, with head of 20 to 40 feet above the lake.

WATER SUPPLIES FOR CITIES AND VILLAGES

Bayfield.—The city water supply is taken from Lake Superior. The sewage, without purification, is emptied into the lake. About 95 per cent of the houses use city water and about 75 per cent are connected with the sewer system. Cess pools are not allowed.

Washburn.—At Washburn, the city water supply is at present pumped from Lake Superior. No sewage system is installed. Artesian flows from the sandstone are possible in this locality, as is shown by the well owned by the Washburn Electric Light and Power Company.

South of Washburn very much the same conditions are encountered as at Superior. Near the shore the sandstone outcrops in places, as it does to the north of the city. The sandstone is struck in the city at the Washburn Electric Light and Power Company's well at a depth of 265 feet.

Iron River.—Iron River, located on a small river of the same name, has a population of about 1,000. A water system for fire protection only is installed, the supply being obtained from the river. The private wells are generally from 20 to 100 feet deep in the drift.

Orienta.—At Orienta, water, somewhat salty, was obtained from wells in sandstone, 150 to 200 feet in depth. Several good springs also occur along the Iron River.

Port Wing.—At Port Wing the water is obtained from the sandstone, and the wells range in depth from 10 to 100 feet. The shallower wells have poor water, and often contain considerable sediment.

Cornucopia, Redcliff and Houghton.—At Cornucopia the supply is chiefly drawn from springs, with a few shallow wells in the drift 10 to 20 feet deep, while at Redcliff the water is obtained from wells in the sandstone 50 to 300 feet deep. Farther south, at Houghton, a sufficient supply is obtained from open wells, dug 20 feet into the sandstone, which at this place is covered by a few feet of red clay.

Bibon, Benoit and Drummond.—At Bibon are several driven wells, 55 to 80 feet deep in drift. At Benoit are a number of dug wells 74 to 104 feet in the sandy drift, yielding 10 to 50 barrels per day. At Drummond a good supply of water is obtained in gravel and sand at 50 to 65 feet. The hard trap rock outcrops in the village but in places a thickness of 100 feet of drift overlies the trap.

Mason.—At Mason, wells find an abundant supply of water from the drift or sandstone at depths of 105 to 135 feet. The well of the White River Lumber Company is 796 feet deep, passing through sandstone and shale below a depth of 145 feet of drift. In section 8, T. 45, R. 5 W., a well was reported by J. A. Colwell in 1900 to penetrate 511 feet of drift, mainly quicksand, before sandstone was reached.

Engoe.—At Engoe only a few settlers have dug shallow wells, most of the water being obtained from springs. Some wells have been put down here and obtained artesian flows. Some wells, however, pass through clay into sand to depths of 180 feet without obtaining water. However, between this place and the lake, flows may be expected in favorable localities as high as 30 to 40 feet above lake level.

QUALITY OF THE WATER

Only three analyses of water of this county are available,—that of the White River at Drummond, which is a soft water and low in mineral content and two analyses of very soft lake waters. The water obtained from lakes and rivers, as well as that from the surface deposits of gravel and sand, associated with the surface deposits of drift and lacustrine clays, is very likely to be relatively soft water, while that obtained from the Lake Superior sandstone is likely to be highly mineralized in some places and possibly salty, while in other places the water from the sandstone especially in shallow wells, may be only hard water of low or moderate mineral content. The mineral analyses of Lake Superior water is shown on page 219.

Mineral analyses of water in Bayfield County.

(Analyses in parts per million.)

	River.	Lake.	
	1.	2.	3.
Silica (SiO_2)	14.4	11.7	9.9
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	7.5	4.0	2.6
Calcium (Ca)	24.5	15.3	14.0
Magnesium (Mg)	7.9	4.1	3.6
Sodium and potassium (Na+K)	2.5	undet.	undet.
Carbonate radicle (CO_3)	56.4	32.6	28.2
Chlorine (Cl)	3.9	0.0	0.0
Organic matter	17.1	0.5	1.9
Total dissolved solids	117.	68.	58.

1. White river at Drummond, 1 to 3 feet deep. Analyst, G. M. Davidson, C. & N. W. Ry. Co., July 22, 1901.
2. Pike Lake, mean of 4 analyses. Analysts, E. B. Hall and C. Juday, Aug. 25, 1908. Wis. Survey Bull. 22, p. 170.
3. Owen Lake, mean of 3 analyses. Analysts, E. B. Hall and C. Juday, Aug. 20, 1908. Wis. Survey Bull. 22, p. 170.

Brown County

Brown County, located at the south end of Green Bay in the eastern part of the state, has an area of 518 square miles and a population of 54,098. About 89.1 per cent of the county is in farms, of which 64.8 per cent is under cultivation.

SURFACE FEATURES

The surface is gently sloping along the Fox river and in the northwestern part of the county, and is somewhat high and undulating on the upland plain in the eastern and southeastern part. The valley of the Fox river from Green Bay to Lake Winnebago is a continuation of the depression or trough occupied by Green Bay. The slope down the Fox river valley from Lake Winnebago to Green Bay is relatively steep, about seven feet per mile, the descent in 29 miles being 166 feet.

A relatively steep cliff of limestone, the Niagara limestone escarpment, extends along the east side of the Fox valley east of which is a higher undulating plain largely drained by streams flowing eastward to Lake Michigan. The drift deposits furnish no characteristic morainic features, but faint traces of the old shore lines and beaches of a former expansion of Green Bay extend up the Fox river valley. The elevations range from 580 feet above sea level along the shore of Green Bay to about 900 feet along the northwestern side of the Green Bay valley, and to about 1,000 feet on the uplands in the southeastern part. The cliffs east of Green Bay valley generally rise quite abruptly from 200 to 250 feet above the level of the valley adjacent.

GEOLOGICAL FORMATIONS

The geological formations which appear at the surface, or lie immediatley beneath the drift are the Galena and Platteville dolomite "Trenton" in the western and northwestern part of the county, and the overlying Cincinnati shale and Niagara limestone in the eastern and southeastern parts. The geological structure is illustrated in the cross section, figure 21.

The usual thickness of the Galena-Platteville is 100 to 150 feet, the maximum thickness where uneroded however probably reaching 200 to 250 feet. The underlying St. Peter sandstone and Lower Magnesian limestone together are usually 140 to 250 feet thick, the Lower Mag-

nesian being variable in character, consisting largely or entirely of sand and shale at De Pere and of sandstone and 80 feet of limestone at Green Bay. The Upper Cambrian (Potsdam) sandstone is probably between 450 and 550 feet thick, being 541 feet thick at Green Bay.

The Cincinnati shale underlying the Niagara has a thickness of 325 feet in the southeastern part of the county at Denmark, and very probably over 500 feet in the northeastern part. The Niagara limestone is of variable thickness, depending upon the extent of its erosion, the maximum thickness in Brown county on the highest uplands probably reaching 400 to 500 feet.

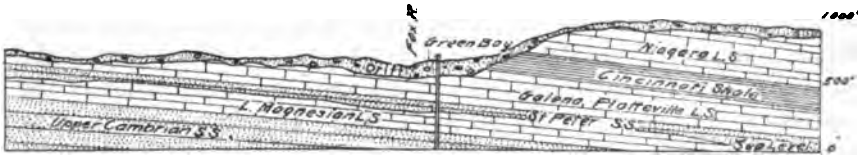

Fig 21.—Geologic section, east-west, across central Brown County.

The thickness of the surface deposits is variable, ranging from 0 to 100 or 200 feet. The red lacustrine and pebbly clay which extends over most of the county varies in a general way from 5 to 20 feet in thickness. In the valley of the Fox the clay is quite free from stone and overlies stratified sands and gravel.

The range in thickness of the geological formations in the county may be summarized as follows:

Probable range in thickness of formations in Brown County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Niagara dolomite	0 to 500
Cincinnati shale	0 to 500
Galena-Platteville (Trenton) dolomite	0 to 250
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	450 to 550
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

Water supplies are obtained from all the geological formations, but the most important sources are the surface deposits of sand and gravel underlying the red clay and the sandstone strata underlying the Galena-Platteville dolomite. The ground water level in the valley of the Fox

river and Duck Creek is usually not far below the surface, generally less than 100 feet. Upon the uplands of the eastern part of the county water can generally be obtained within 100 or 200 feet of the surface. The shale underlying the Niagara is impervious and there are also some shaly seams within the dolomite which favorably influences the water-bearing conditions of the Niagara.

FLOWING WELLS

Water contained within the sandstone underlying the Trenton limestone is under strong pressure and in the low ground of the Fox river valley and adjacent to Green Bay strong flows are developed. Flowing wells from the surface deposits are not known to occur in this county, though they may be present.

The flowing wells and artesian conditions are described more fully under the water supplies for Depere, Green Bay and Big Suamico. At Big Suamico the head is 45 feet above the surface, at Green Bay it originally was 97 feet, and at Depere 92 feet above the surface. At present, however, on account of the pumpage and leakage from the artesian reservoir, the normal head is only 9 feet above the surface at Green Bay and 12 feet at Depere.

The strongest artesian flows in Wisconsin, as developed originally, occur at Depere and Green Bay. At Depere the pressure, 40 pounds per square inch, was sufficient to convey the water over the city for domestic and city purposes. At present a pumping plant and storage reservoir are installed.

SPRINGS

Springs are a common source of water supply in the eastern part of the county at the base of the limestone escarpment or ledge east of Green Bay. In this locality, wherever the shale outcrops along the bluff, springs are likely to issue either directly from the shale or from the overlying drift some distance from the ledge.

Within the city of Green Bay are several well known mineral springs whose source appears to be in the drift overlying "Trenton" limestone.

WATER SUPPLIES FOR CITIES AND VILLAGES

Green Bay.—This city, located at the junction of the Fox river and Green Bay, has a population of 25,236. The city water supply is obtained from nine 8-inch wells 911 to 913 feet deep, striking the granite

floor at about 910 feet. The sewage without treament is emptied into the Fox river. About 65 per cent of the houses are connected with the city water supply and the sewage systems.

The wells furnishing the city water supply are cased 400 to 450 feet in order to prevent leakage. The wells after being packed originally flowed about 1,000,000 gallons per day. When the first city wells were drilled, the water rose 97 feet above the surface. At present the normal head is 9 feet above the surface. On account of the lowering of the artesian head by sinking other wells the normal flow became insufficient and an air lift system was installed. The air pipes extend 180 feet into the wells and with 85 pounds pressure it is possible to secure 2,000,000 gallons per day. When the air pressure is applied it stops the flow of nearly all the other wells in the city and lowers the water in the eight wells to a depth of 30 feet. The water is discharged into a large covered reservior. The average daily pumpage in 1910 was 1,305,000 gallons. The most recent well drilled by the Water Company (in Jan. 1914) is reported to have a depth of 837 feet and diameter of 20 inches. A large flow of water was struck at a depth of 500 feet and the flow was gradually increased as the well was sunk to a greater depth.

The log of the city wells, as given by W. G. Kirchoffer, is as follows:

Section of Green Bay Waterworks Wells.

Formation.	Thickness.
	Feet
Pleistocene Drift	100
Platteville Limestone	130
St. Peter Sandstone	80
Lower Magnesian Limestone	60
Upper Cambrian (Potsdam) Sandstone	[illegible]41
Depth	913

Eight of the wells, those put down in 1901, were tested with the following results:

Test of Green Bay Wells.

At 577 feet 60 gallons per minute.
At 650 feet 100 gallons with a pressure of 16 pounds.
At 735 feet 150 gallons with a pressure of 40 pounds.
At 825 feet 180 gallons with a pressure of 49 pounds.

These tests show a steady increase in pressure and flow on approaching the bottom layers of the Upper Cambrian sandstone.

Besides these wells there are at least 30 other wells within the city drawing water from the Upper Cambrian strata, all of them using large quantities of water.

In addition to the Green Bay deep city wells there are numerous wells that terminate in the St. Peter sandstone which are partially dependent for their supply upon water from the underlying sandstone horizon. West of the river, there are very many wells scattered through the city and country as far as Duck Creek northwest of Green Bay. They are too numerous to give a detailed account of but one record may be given for West Green Bay, which will serve as a type.

Section of well, elevation of curb, 600 feet; owned by Ernest Smith, West Green Bay.

Formation.	Thickness.
	Feet.
Clay	78
Galena-Platteville dolomite	142
St. Peter sandstone	83
Total	303

The private wells in Green Bay that enter the Potsdam sandstone are much like the deep city wells, and the strata passed through may be judged from the records of the latter. Mr. Charles Green, a well driller of Green Bay, states that the St. Peter sandstone in Green Bay is very irregular. In places it is 80 to 100 feet thick, as in the Waterworks wells and at one of the wells in West Green Bay, at other places it does not exceed 6 to 10 feet, and in some places it was not found at all. In these cases the "Trenton" limestone apparently rests directly upon the Lower Magnesian limestone and the thickness of the combined limestones is somewhere between 250 and 300 feet. The same thing without doubt occurs at the other places along the Green Bay shore north of Green Bay and accounts for the greater thickness of limestone in certain of those wells. Mr. Green further states that at De Pere and also north of Green Bay to Oconto he finds the St. Peter sandstone much thicker than at Green Bay. At Depere it reaches a maximum thickness of 150 feet. The St. Peter seems to occur in pockets in and about Green Bay. Whereever the St. Peter sandstone is very thick, no Lower Magnesian limestone is found, the sandstone being underlain by red marl and shale and then by the Potsdam sandstone. Similar conditions occur farther south.

The decrease in water supply about Green Bay is not due to the decrease in the supply at the source, as so many are inclined to think, for the wells nearer the gathering ground show no decrease in their flow or

head. It must, therefore be due, to the inability of the aquifer to transmit a sufficient water to the wells to supply the increased local demand.

De Pere.—This city located on the Fox river has a population of 4,-477. The city water supply is obtained from artesian wells.

The old system, using direct well pressure, was superseded in 1905 by pumping into elevated tanks, an entirely separate and complete system being installed for each side of the Fox river. The same wells were used as formerly, and in addition, the city purchased one situated on the east side, the site of the old dock and furnace. Three wells are used on the East Side, and two on the West Side, the depth of the wells ranging from 800 to 840 feet, the diameter of each being 5 to 8 inches. The average daily pumpage is 130,000 gallons. The sewage, without purification, empties into the Fox river. About 75 per cent of the houses are reported to have water supply and sewer connections.

The wells at De Pere are within the artesian basin about Green Bay, and are affected in their supply in the same way as at the city of Green Bay. Owing to only a thin strata of sand to a depth of 12 to 15 feet over the rock the water from surface wells here are generally unfit for domestic use and early attempts were made to get a supply from deeper sources.

In 1886 East De Pere sunk its first well, six inches in diameter, 830 feet deep, in order to obtain a city supply. When first drilled there was a pressure of over 40 pounds to the square inch and the water rose 92 feet above the surface. The flow as estimated at that time amounted to more than 1,000,000 gallons every 24 hours. The pressure was utilized in conveying the water over the city for domestic and city purposes, and for fire protection. In 1893 another well was put down by the East De Pere Water Supply Company, about three-fourths of a mile east of the old well. The number of wells later put down greatly reduced the pressure and flow, and in 1904 the city wells had a pressure of only about 12 pounds per square inch, and barely raised the water to the second floor of the houses. About 200 consumers were supplied in East DePere by the direct well pressure when this system was superseded by the present systm in 1905.

The West De Pere Water Company put down two wells 8 inches in diameter and 800 feet deep. The flow at first was over 1,000,000 gallons every 24 hours, with a pressure of 42½ pounds per square inch, but in 1905 the capacity was about 400,000 gallons every 24 hours with a pressure of about 12 pounds per square inch. About 160 consumers were formerly supplied in West DePere on this direct pressure system. On account of the great waste of water and falling pressure pumping plants were built on each side of the river, as above described.

There are between 20 and 30 wells in DePere that draw their water from the sandstone under the Trenton formation. The St. Peter, Lower Magnesian and Upper Cambrian (Potsdam) formations cannot be easily differentiated at DePere, since the Lower Magnesian is either absent or is largely sandstone, as illustrated in the following log of the St. Norbert College well, as interpreted by F. T. Thwaites:

Log of well of St. Norbert College, De Pere, elevation of curb 611 ft. drilled in 1902.

Formation.	Depth.	Thickness.
	Feet.	Feet.
Pleistocene:		
Yellowish sand	0- 50	50
Galena-Platteville (Trenton):		
Gray-blue limestone	50-145	
Blue shaly limestone	145-175	
Fine calcareous white quartz sandstone	175-185	
Gray and blue limestone	185-190	
Medium grained, gray quartz sandstone and blue shale	190-202	
Soft blue calcareous shale	202-225	175
St. Peter:		
Fine grained, pure quartz sandstone	225-325	
Very fine pinkish sandstone	325-340	115
Lower Magnesian:		
White chert and greenish shale	340-350	10
Madison:		
Fine yellowish quartz sandstone	350-365	
Pure white sandstone	365-400	
Ferruginous sandstone	400-425	75
Mendota:		
Pink calcareous shaly sandstone	425-440	
Greenish shale and some gray limestone	440-460	
Brick red sandstone	460-475	50
Potsdam:		
Fine brownish sandstone	475-520	
Pinkish quartz sandstone	530-560	
Pure white sandstone	560-635	
White sandstone with some blue shale	635-680	
Pure white sandstone	680-800	325
Total depth		800

The generalized section of two other wells in DePere are as follows:

Sections of wells at Depere.

Formation.	West Depere city well.	Goodenough paper mill well.
	Thickness.	Thickness.
	feet.	feet.
Pleistocene.		
Sand and gravel	80	22
Galena-Plattesville.		
Limestone	120	137
St. Peter, Lower Magnesian, and Upper Cambrian (Potsdam.)		
Sandstone	640	657
Total depth	840	816

The well at the paper mill 816 feet deep is said to reach granite, and also the one at West DePere 840 feet deep. The chief water veins are found at depths of about 300 and 500 feet. In order to get highest pressure the wells should be packed so as to shut out leakage into the overlying limestone. In many wells this was neglected and the crevices offered a ready means of escape for much of the water.

Big Suamico.—At Big Suamico flowing wells occur like those in Green Bay. The well of Wm. Malchow, 284 feet deep, has a head 45 feet above the surface. This well passed through 60 feet of surface sand, 200 feet of Trenton limestone, and 24 feet of St. Peter sandstone.

Askeaton.—The log of the well at the cheese factory, near Askeaton, in S. E. of section 33, is as follows:

Log of well at Askeaton.

Formation.	Thickness.
	Feet.
Probably drift, no record	100
Cincinnati Shale:	
Gray to bluish calcareous clay	200
"Trenton" Limestone.	
Gray limestone	199
St. Peter Sandstone.	
Gray sandstone	35
Total depth	534

Denmark.—The railroad well at Denmark, 975 feet deep, analysis of the water of which is given in the table, has the following record of the formations penetrated:

Log of C. & N. W. well at Denmark.

Formation.	Thickness.
	Feet.
Clay (surface)	137
Lime rock (Niagara)	268
Shale (Cincinnati)	325
Lime rock (Galena-Platteville)	179
Sandstone (St. Peter)	66
Total	975

Wrightstown.—This village, population 525, located on the Fox River, obtains its water supply from private wells ranging in depth between 15 and 200 feet. The surface formation is red clay containing some sand and gravel seams.

Mill Center.—The section of the well of Jeff Kimbs at Mill Center in the town of Pittsfield, in the northwest part of the county is shown in the following log:

Log of well at Mill Center.

Formation.	Depth.	Thickness.
	Feet.	Feet.
Pleistocene	No sample.	137?
Galena-Platteville		
Gray dolomite	137-180	43
St. Peter		
Sandstone	180-215	35
Lower Magnesian		
Sandstone and colcareous red shale	215-275	
Shale and dolomite	275-315	100
Total depth		315

THE QUALITY OF WATER SUPPLIES

The mineral analyses of the water shows a considerable variation in the character, depending on the source of the supply. The spring water at Green Bay, and the Fox River water at Green Bay and DePere, are hard waters while that obtained from the deep wells in DePere, from the St. Peter and Upper Cambrian sandstones, is very hard water though of only moderate mineral content. The water from the shallow 76-foot well near Denmark, either in the glacial drift or Niagara limestone, is also a very hard water. The deep railroad well at Denmark, 975 feet deep, has very hard water, high in mineral content, while the deep well at Askeaton, 1,000 feet deep, has very hard water, high in mineral content and is distinctly salty. Both of these deep wells at Denmark and Askeaton have their source of supply in the St. Peter or the Upper Cambrian sandstone underlying the thick Cincinnati shale and the Trenton limestone. Calcium is the predominating basic constituent though sodium is abundant in the deep Askeaton well. All the waters are corbonate waters except that from the deep Askeaton well in which sulphates and chlorides are much more abundant than the carbonates.

The Fox river water at Green Bay, No. 2, contains 1.29 pounds of incrusting solids in 1,000 gallons, while that from the well at Denmark, No. 15, contains 5.35 pounds in 1,000 gallons.

Mineral analyses of water in Brown County.

(Analyses in parts per million.)

	River.			Spring.		Surface deposits.			
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Depth of well.......feet:	....	....	....	....	....	....	94	25′	60′
Silica (SiO_2)............		2.5	7.0	20.0	21.	20.0	undet.		
Aluminum and iron oxides($Al_2O_3+Fe_2O_3$)	1.5	0.8	2.9		1.2	3.2	undet.	39.5	3.4
Aluminum oxide (Al_2O_3)	....	....	....	2.5	....	....	....	....	....
Iron (Fe).........................	....	....	....	.7	....	....	....	....	....
Calcium (Ca)............	38.2	32.5	34.9	24.8	87.4	36.8	18.7	107.0	45.9
Magnesium (Mg).........	19.7	19.0	19.8	22.0	43.4	19.1	10.7	108.0	34.6
Sodium (Na).............	8.7	12.7	6.0	8.2	20.8	18.4	5..6	13.8	33.7
Potassium (K)............				4.4	1.7				
Carbonate radicle $(CO)_3$	99.4	88.8	99.2	56.4	183.	46.9	82.4	195.	195.
Sulphate radicle (SO_4)...	23.2	11.1	13.3	27.8	58.8	88.6	44.7	....	trace
Chlorine (Cl)..............	3.9	19.5	1.9	38.0	31.	28.4	13.4	21.9	1.9
Organic matter...........	....	11.6	6.6	....	26.5	....	....	9.1	....
Total dissolved solids....	195.	198.	192.	205.	475.	261.	223.	722.	315.

	Surface deposits.	Drift and Niagara.	St. Peter and Upper Cambrian (Potsdam) sandstone.				
	10.	11.	12.	13.	14.	15.	16.
Depth of well.....feet..	63	73	130 & 360	840	800	975	1,000
Silica (SiO_2)............	undet.	20.2		7.2	30.7	18.3	6.8
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)...	undet.	0.5	1.7			6.1	
Alumin'm oxide (Al_2O_3)	....	....	....	.9	.9	....	....
Iron (Fe)..........................	....	....	....	.6	.8	....	....
Calcium (Ca)............	50.0	69.2	28.5	54.4	60.2	179.5	373.8
Magnesium (Mg)........	38.9	44.0	13.1	46.9	34.4	55.7	47.8
Sodium (Na).............	43.0	7.7	52.3	20.6	12.7	39.1	165.0
Potassium (K)...........				16.2	11.2		
Carbonate radicle (CO_3)	186.3	192.3	92.1	154.3	176.2	171.2	120.3
Sulphate radicle (SO_4)..	17.6	48.4	61.1	104.8	24.1	133.3	919.0
Chlorine..................	33.6	9.5	14.8	21.6	12.2	23.2	253.7
Undet. soluble matter..	....	....	....	....	....	26.0	....
Total dissolved solids..................	369.	392.	264.	427.	363.	652.	1,886

1. Fox River and Reservoir, Green Bay Shops, Green Bay. Analyst, Chemist C. M. & St. P. Ry. Co., July 9, 1897.
2. Fox River at Green Bay. Analyst, G. M. Davidson, Sept. 17, 1907.
3. Fox River at De Pere. Analyst, G. M. Davidson, Feb. 8, 1892.
4. St. John Mineral Spring, Green Bay. Analyst, W. Daniells for M. Holgknecht.
5. Allouez Mineral Water, Green Bay. Analyst, U. S. Bureau of Chem., 1905.
6. Well at Green Bay. Analyst, Milwaukee Ind. Chem. Institute.
7. Well & Reservoir of C. M. & St. P. Ry. Co., Green Bay. Analyst, G. N. Prentiss, Feb. 6, 1912.
8. Well of C. M. & St. P. Ry. Co., Greenleaf. Analyst, G. N. Prentiss, Oct. 16, 1902.
9. Well of C. M. & St. P. Ry. Co., Askeaton. Analyst, Chemist C. M. & St. P. Ry. Co., Jan. 1, 1892.
10. Wells and Reservoir of C. M. & St. P. Ry. Co., Askeaton. Analyst, G. N. Prentiss, Feb. 7, 1900.
11. Flowing well 5½ miles southwest of Denmark. Analyst, G. M. Davidson, July 15, 1907.
12. Two wells of C. M. & St. P. Ry. Co. shops, Green Bay. Analyst, Chemist C. M. & St. P. Ry. Co., July 11, 1891.
13. The City Well at East De Pere. Analyst, W. W. Daniells.
14. City Well at West De Pere. Analyst, W. W. Daniells.
15. Well of C. & N. W. Ry. Co., Denmark. Analyst, G. M. Davidson, Sept. 13, 1907.
16. Railroad well at Askeaton. Analyst, Chemist C. M. & St. P. Ry. Co., April 4, 1891.

BUFFALO COUNTY

Buffalo county located in the western part of the state, has an area of 662 square miles and a population of 16,006. About 92.8 per cent of the county is laid out in farms, of which 49 per cent is under cultivation.

SURFACE FEATURES

The surface consists of alternating uplands and valleys, the latter trenched relatively deep near the Mississippi river, as much as 500 feet below the general upland area. The uplands are generally covered with silt loams, while the valley bottoms are covered with sandy loams of alluvial origin. The valleys of the Mississippi, Chippewa and Beef rivers are flat bottomed and filled with alluvial sand and gravel while the small

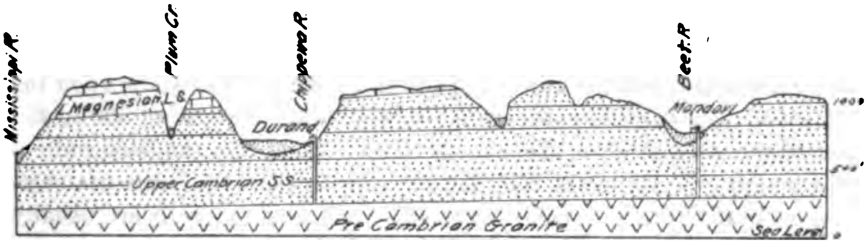

Fig. 22.—Geologic section, east-west, across Buffalo and Pepin counties.

stream valleys are relatively narrow. The altitudes range from less than 700 feet along the Mississippi river to 1,200 or 1,300 feet on the uplands.

GEOLOGICAL FORMATIONS

The rock formations are the Upper Cambrian (Potsdam) sandstone and shale, with the Lower Magnesian limestone capping the highest ridges in all parts of the county, except the northeastern corner. The surface formations are the loess on the uplands and the alluvial deposits in the valley bottoms. The geological structure is illustrated in Fig. 22.

The thickness of the alluvial deposits in the valleys may possibly reach a maximum of 200 feet. The thickness of the Upper Cambrian sandstone and the Lower Magnesian limestone is variable on account of the extensive erosion of the strata. The complete thickness of the sandstone is present only where protected by the overlying Lower Magnesian

limestone formation. The limestone attains its greatest thickness on the highest ridges. The depth at which the Pre-Cambrian granite floor is reached is 418 feet below the surface of the valley bottom of the Beef River at Mondovi, and about 500 feet below the surface along the valley bottom of the Mississippi.

The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Buffalo County.

Formation.	Thickness.
	Feet.
Surface formation	0—200
Lower Magnesian dolomite	0—200
Upper Cambrian (Potsdam) Sandstone	300—800
The Pre-Cambrian Granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the Upper Cambrian (Potsdam) sandstone and the alluvial sands and gravels. The wells upon the limestone divides quite generally have to go down a depth of 300 to 400 feet to the general water level in the Upper Cambrian sandstone to obtain a supply. Along the Mississippi river bottoms the wells are shallow, generally from 20 to 100 feet deep. In Nelson the wells are usually in sandstone from 25 to 50 feet in depth. In Cochrane, the wells are from 15 to 35 feet in sand.

FLOWING ARTESIAN WELLS

Flowing artesian wells in the Potsdam sandstone, at Fountain City in the valley of the Mississippi, and at Mondovi and north of Alma in the valley of the Beef River, are important sources of supply at these localities.

Artesian flows have apparently not been sought at any other place along the Mississippi River in Buffalo county than at Fountain City. It is to be expected, however, that flows can be struck all along the river on low ground above Fountain City, similar to the flows obtained between Fountain City and La Crosse. The underground conditions at Fountain City are about the same as at La Crosse and Onalaska, and Winona, Minnesota, where important flows are obtained. The maximum head at Fountain City is about 40 feet above the Mississippi River.

Flows should be obtained not only on the low ground of the Mississippi flats, but also on the tributaries of the Misissippi, or in the "coolies" leading up into the ridges from the main valley. Flows have been struck in some of the larger valleys, as illustrated by the flowing wells near the mouth of the Beef River and at Mondovi, far up the valley. This region promises good returns to the careful prospector. Further details concerning the flowing wells in Fountain City and Mondovi are given on the following pages.

Since the above statement was sent to the press it has been learned that during 1913 and 1914 about 20 flowing wells were drilled in the Beef Valley within 5 or 6 miles above and below Mondovi. The wells are usually drilled through the sandstone to the granite, to depth of 400 to 450 feet. The artesian head is usually 6 to 8 feet, in some wells reaching up to 10 feet, above the well curbs and about 30 to 40 feet above the level of the Beef river adjacent. The maximum pressure is said to be reached in many of the wells at depths of 280 to 300 feet.

The bottom lands throughout the Beef valley, and also in many of the tributary valleys, should be favorable localities for the development of flowing artesian wells. The wells should be properly cased so that the artesian heads will be preserved at the maximum heights. The water from the artesian wells should not be allowed to run to waste but the flows should be shut off when not in use, otherwise the artesian pressure in the district will be gradually lowered until the wells cease to flow.

Automatic pumps, a modification of the hydraulic ram, are installed at many of the wells for the purpose of driving the water from the artesian wells up into the farm-houses and barns. These automatic pumps produce 10 or more gallons per minute from a 5 or 6-foot head and are reported to be satisfactory in all respects.

WATER SUPPLIES FOR CITIES AND VILLAGES

Alma.—Alma, the county seat, on the Mississippi River, has a population of 1,011. The city is built on a relatively steep slope bordering the river, on the outcropping Upper Cambrian (Potsdam) sandstone and shale. The private wells obtain their supply from the sandstone and are generaly from 10 to 100 feet deep, depending upon elevation above the river.

A flowing artesian well was recently obtained on the farm of F. Gleiter about three miles north of Alma on the Beef River. The formations penetrated are as follows:

Log of F. Gleiter's flowing well near Alma.

Formation.	Thickness.
	Feet.
Surface	103
Blue Rock	90
Sandrock	207
Total depth	400

The water flows about 24 feet above the level of Beef River. The first flow was struck at a depth of about 207 feet and a second flow at depth of about 250 feet.

Fountain City.—This city, located on the Mississippi river, has a population of 1,031. The city supply is obtained from a 4-inch artesian well 300 feet deep. Four of the artesian flowing wells in Fountain City are as follows:

Artesian wells in Fountain City.

Owner.	When drilled.	Size (in.)	Depth feet.	Depth to rock.	Elevation of curb.	Water rises above curb.
City	1895	4	300	75	670	20
John Baecheler	1900	6	365	80	663	25
Brewing Company	1896	6	350	80	685	0
Creamery	1900	4	220	80	665	13

All these wells are cased to rock. The city well ordinarily has a flowing capacity of 383 gallons per minute. The temperature of the water is 51° F. Most of the water supply for the city is derived from private wells about 50 feet deep in the gravel and sand.

The artesian wells at Fountain City get their supply from the Upper Cambrian (Potsdam) sandstone. The first 75 to 80 feet in surface deposits is reported as sand, clay and gravel, mostly gravel. The Potsdam sandstone is mostly a white sandstone. The water from the lower horizon contains more iron than that from the upper horizon and for this reason was not used at the city creamery.

All of these wells show a marked increase in flow and pressure whenever the river is high, which indicates that there is considerable influence exerted by the weight of the groundwater on the artesian head. This fluctuation may be best observed in the city fountain where the flow is comparatively small due to the higher elevation.

Mr. Baecheler's well is on the lowest ground, and if allowed to flow freely will stop the flow in the city well and greatly reduce the heads of the other wells which lie within a few blocks of it. The four artesian flowing wells are within a few blocks of each other.

Mondovi.—Mondovi, located on Beef River, has a population of 1,325. The public water supply is obtained from a 10-inch well 418 feet deep. The well penetrated 68 feet of sand and gravel, and 350 feet of sandstone, striking granite at bottom. Water was first struck at 28 feet; at 200 feet water began to rise in the well; at 300 feet it reached the surface of the ground; and at depth of 360 feet the well flowed 75 gallons per minute. The well has yielded 400 gallons per minute under suction for 10 hours. Continuous pumping for four or five hours lowers the water in the well so that it does not flow for one-half to two hours after pumping is stopped. Another similar well was drilled on Mr. Meyer's place. The well is not quite so deep and is located too high to flow at the surface. Other flows could be obtained on low ground in the village and for some distance up and down Beef River.

The city sewerage is emptied without purification into the river.

QUALITY OF THE WATER

No complete analyses are available of the water supplies of Buffalo County. It seems very likely, however, that the water obtained from the alluvial sand, as well as that from the sandstone formation, will be found to be hard water. The groundwaters are likely to contain only 200 to 300 parts per mililon of dissolved solids. The groundwater supplies are likely to be somewhat more highly mineralized than the surface waters from the Mississippi and other rivers. Very little water is probably obtained from the limestone formation capping the upland areas, but where the limestone or the underlying sandstone is the source of supply it is very probably hard water, like that in wells at La Crosse (see page 416.)

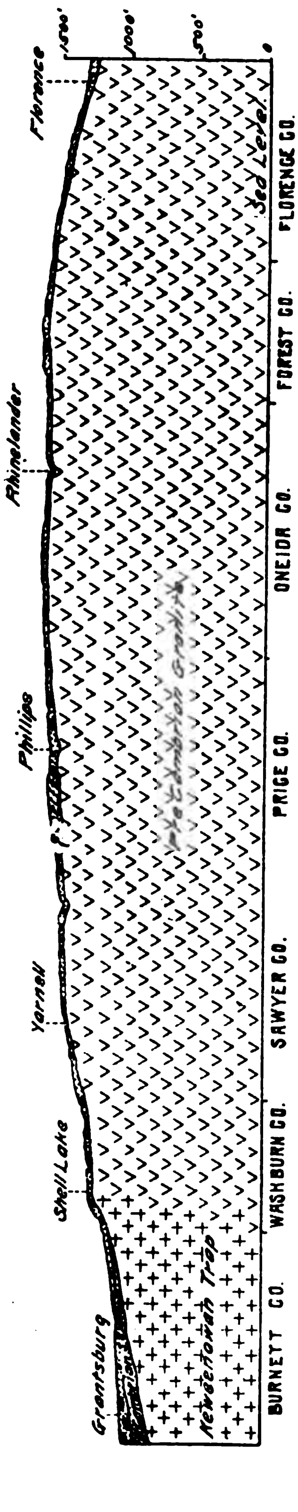

Fig. 23.—Geologic section, east west, across Burnett, Washburn, Sawyer, Price, Oneida, Forest and Florence counties. In these counties the water supply is mainly derived from the glacial drift or alluvial sand overlying the Pre-Cambrian crystalline rocks.

BURNETT COUNTY

Burnett County, located in the northwestern part of the state, has an area of 881 square miles, and a population of 9,026. About 40 per cent of the county is in farms of which about 25 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is quite level throughout, the only exception being the broad ridge of Keweenawan trap, extending northeast through the southeastern part of the county. Much of the central and western parts is a broad sandy plain. The St. Croix River is intrenched deeply in the plain on the western boundary. The general altitude of the plain about Grantsburg is 900 to 1,000 feet while altitudes on the trap ridge reach 1,200 to 1,300 feet.

The principal drainage lines are the Wood, Clam and Yellow rivers, flowing west and northwest to the St. Croix. Many lakes lie in the southeastern and northeastern parts, among which may be mentioned Trade, Big Wood, Clam, Big Sand, Yellow, Fish and McKenzie lakes.

GEOLOGICAL FORMATIONS

The geological formations of the county are the trap in the southeastern part, and the Upper Cambrian sandstone in the western part, and the surface formations distributed over the entire county. The sandstone, however, is effectually covered with surface for-

mation, with exception of a few outcrops along the St. Croix river. The surface formations consist of glacial drift, mainly confined to the morainic ridges in the southeastern part, and the broad, nearly level plain, consisting of sand, gravel and stratified clays, in the central and western parts The thickness of the various formations varies greatly. The Keweenawan trap formation is practically unlimited in depth, as this formation is erupted from deep seated sources; hence, it is useless to attempt to penetrate through this formation when encountered in drilling wells. The sandstone formation, underlying the surface deposits in the central and western parts, probably does not exceed a thickness of 100 to 200 feet, and is probably underlain either by the trap or by granitic formations. The glacial drift, consisting of boulders, sand and gravel mixed with some clay, ranges in thickness from a few feet up to 100 or 300 feet. The surface sand, usually underlain by the stratified clay deposits, forming the broad, level areas of the county, is variable in thickness on account of the uneven surface of rock upon which it was deposited. The sand and clay formations usually range in thickness from 50 to 200 feet, and may reach 300 feet in places.

The geological structure of Burnett and other counties in the northern part of the state, where only the surface formations overlie the Pre-Cambrian granite, is illustrated in Fig. 23.

The approximate range in thickness of the formations in Burnett County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Sandstone	0 to 200
Keweenawan trap	....

PRINCIPAL WATER-BEARING HORIZONS

The principal source of water supply is the surface formation of sand and gravel. Where the sandstone is reached in some of the deeper wells a good supply is readily obtained. The trap, however, is relatively impervious and furnishes a small supply only where much fractured. A good supply can generally be obtained at the contact of the trap with the overlying surface formation, where the latter has a thickness of 20 or 30 feet, or more.

WATER SUPPLIES FOR CITIES AND VILLAGES

Grantsburg.—This city (population 721) is located upon the Wood river in western Burnett County. No city water supply system has been installed. The formation is stratified alluvial sand and clay to a probable depth of at least 100 feet, overlying the sandstone. An abundant supply of water is easily obtained from this alluvial sand formation. Wells are generally from 10 to 75 feet deep.

QUALITY OF WATER SUPPLIES

Only one analysis of the water of Burnett County is available, namely that of a well water at Grantsburg which is hard water. Where the water supply is obtained from formations directly or indirectly associated with the stratified clays which are calcareous, or with the limestone-bearing glacial drift, the water is probably hard water. Where the supply is obtained from nearly pure sand overlying the clay, or from very sandy drift, the supply is likely to be soft water. The water obtained from the trap rock may be highly mineralized in some places and in other places may contain only a small amount of mineral matter.

Mineral analyses of water in Burnett County.

(Analyses in parts per million.)

	Surface deposits.
	1
Depth of well ... feet..	20
Silica (SiO_2)	15.9
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	1.1
Calcium (Ca)	36.0
Magnesium (Mg)	14.4
Sodium and potassium (Na+K)	8.9
Carbonate radicle (CO_3)	82.5
Sulphate radicle (SO_4)	11.2
Chlorine (Cl)	13.8
Total dissolved solids	184.

1. Well at Grantsburg. Analyst, Dearborn Drug & Chem. Co., Jan. 26, 1905.

CALUMET COUNTY

Calumet County, located in the eastern part of the state, east of Lake Winnebago, has an area of 317 square miles, and a population of 16,701. About 94.8 per cent of the county is in farms, of which 73.4 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is a relatively high undulating plain, with a gentle slope in the central and eastern part towards Lake Michigan, and a more abrupt slope to the west in the western part towards Lake Winnebago and the valley of the Fox river. The central and eastern part is drained mainly by the Manitowoc river flowing eastward to Lake Michigan. The western part is drained by short streams flowing into Lake Winnebago and the Fox river.

Upon the relatively high upland portion of the central and eastern part of the county the altitudes of the valley bottoms range from 800 to 950 feet, while the upland ridges along the divides reach up to 1,000 and over 1,200 feet. The highest land in the county is in the southwestern part, a short distance east of Lake Winnebago. The surface of Lake Winnebago has an altitude of 747 feet, and the broad valley bottom at the north end of the lake lies between 750 and 850 feet.

The most prominent relief in the county is the steep escarpment or ridge of the Niagara limestone on the east side of Lake Winnebago, which rises abruptly 200 to 400 feet above the lake.

GEOLOGICAL FORMATIONS

The principal rock formation in the central and eastern part of the county is the Niagara limestone. On the low ground in the western and northwestern part adjacent to Lake Winnebago is a narrow belt of Cincinnati shale and north of the lake is an area occupied by the Galena-Platteville (Trenton) limestone. The drift is generally quite abundant over the entire county. The geological structure along the southern boundary of Calumet and Manitowoc counties is illustrated in Fig. 24.

The thickness of the drift is variable but is generally much greater in the Fox River valley than on the high upland to the east. In the vicinity of Forest Junction are many wells 50 to 200 feet deep in the drift without striking rock. At Brillion many of the wells strike rock at 100 to

150 feet. Most of the surface drift of the county is red clay mixed with some stone and gravel.

The Niagara formation of limestone lies east of Lake Winnebago, Sherwood and Forest Junction. The formation varies in thickness from less than a foot along the western margin of its outcrop to a probable maximum thickness of 300 or 400 feet on the upland ridges in the eastern part of the county.

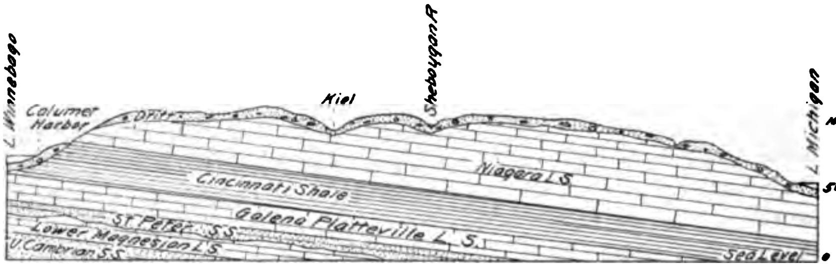

Fig. 24.—Geologic section, east-west, along southern boundary of Calumet and Manitowoc and northern boundary of Sheboygan counties.

The Cincinnati shale which underlies the Niagara limestone and outcrops in a belt one to five miles wide along the western border of the Niagara has a known maximum thickness of 300 feet where uneroded, as shown by the deep well at Chilton. Along the east shore of Lake Winnebago, south of Clifton, about 175 feet of this formation is exposed above the level of the lake. The altitude of the contact with the Niagara at Lake Winnebago is about 920 feet, and at Chilton 679 feet. The shale is a relatively soft formation and therefore is easily eroded. The formation is impervious.

The Galena-Platteville (Trenton) limestone, within its area of outcrop north of Lake Winnebago in the Fox River valley is eroded to a variable extent. Where uneroded it has a known thickness of 225 feet.

The approximate range in thickness of the formations in Calumet County may be summarized as follows:

Probable range in thickness of formations in Calumet County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone	0 to 400
Cincinnati shale	0 to 300
Galena-Platteville (Trenton) limestone	200 to 250
St. Peter and Lower Magnesian formation	200 to 250
Upper Cambrian (Potsdam) sandstone	500 to 600
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing formations are the surface deposits, the Niagara limestone in the central and eastern part, and the Trenton limestone in the northwestern part.

The drift is the most common source of supply, the water level being near the surface in the valleys and usually less than 100 feet from the surface on the slopes of the hills. Shallow open dug wells are common in the drift on the uplands in all parts of the county, the depths of the wells being 10 to 40 feet. In recent years, however, most of the new wells are being drilled, the supply being obtained at greater depth in the drift or from the underlying rock. Between Chilton and Brillion are many drilled wells from 100 to 200 feet deep.

The Niagara limestone is an important source of supply on the high uplands. The formation contains numerous open fractures and fissures and on the gentle slopes of the hills where the drift is 50 or 60 feet thick, abundant supplies are usually obtained from this formation.

The Cincinnati shale is impervious to water, hence no supplies are obtained from this formation. The shale, however, exerts a strong influence on the underground water supply because of its impervious character. Hundreds of springs issue along the outcrop of this formation, the source of the supply being in the overlying drift or Niagara limestone. Wells within striking distance of the shale generally obtain an abundant supply when this formation is reached.

FLOWING WELLS

Flowing wells in the surface deposits and in the Niagara limestone are an important source of water supply in various parts of Calumet county.

Along the northeast shore of Lake Winnebago no flows are obtained except in the vicinity of Stockbridge. A mile north of Stockbridge the high cliff leaves the lake and swings toward the east, leaving a somewhat level area between the ridge and Lake Winnebago. Along this gentle slope flowing wells are struck on the low ground along the east shore of the lake as far south as Fond du Lac, and south of the lake as far as Byron and Oakfield.

The wells in the vicinity of Stockbridge and Brothertown range in depth from 60 to 90 feet, none of them striking rock.

Nearly all of the flowing wells lie on the west side of the old Military Road leading from Stockbridge to Fond du Lac. A few flows have been obtained east of this road, but for the most part the land is rather too

high for flows. Between Stockbridge and Brothertown about 25 or 30 of these flowing wells may be seen along the road. Some of the wells are decreasing in rate of flow, others are as strong as when originally drilled. Flows ought to be obtained on low ground east of the road along the small valleys and streams. In places they are obtained as high as 100 feet above the level of Lake Winnebago. As a rule the flows on the higher land are weak, the water rising only a few feet above the surface. As along the Fox river, the local topography must always be taken into consideration before predicting a flow. (For description of flowing wells south of Brothertown, see under Fond du Lac County, pages 335–6).

In the northeastern part of the county at Brillion, located in a small valley tributary to the Manitowoc river, local conditions favorable for an artesian slope are developed in the surfoce deposits overlying the Niagara limestone. The flowing wells are from 50 to 150 feet deep, the source of the flows being in gravel beds underlying clay seams, and in the underlying shell rock. The heads are relatively low and the wells usually interfere with one another. An account of these wells is given under Brillion and Forest Junction on the following page.

Flowing wells, with source of supply in the sandstone strata underlying the Trenton limestone, are not likely to be developed in Calumet County, on account of the relatively high altitude of the land surface. In one of the deep wells of the Malting Co., at Chilton, which penetrates through the overlying formations and reaches into the St. Peter and Lower Magnesian, water was found in the Trenton, which rose to within 32 feet of the surface, but dropped to 75 feet below the surface on entering the St. Peter sandstone, where it remained

SPRINGS

The important spring horizon; found at the upper surface of the Cincinnati shale, extends across Calumet County along the foot of the "ledges"—east of Lake Winnebago. While springs are common in this horizon, they are not so numerous as they would be if it were not for the impervious covering of clayey drift that overlies the shale. While there are many springs on the west slope of the ridge that help feed the gravel beds, much of the water from the contact zone between the Niagara limestone and the Cincinnati shale usually does not come to the surface, but remains beneath the clay strata in the drift and furnishes the supply for the flowing wells.

Springs are also quite common in the area of the Niagara limestone within the lower slopes of the valley of the Manitowoc river and its tribu-

taries. In many places the springs issue from the limestone, where overlain by the clay drift, as at Brillion.

WATER SUPPLIES FOR CITIES AND VILLAGES

Chilton.—Chilton, situated on the Manitowoc river, has a population of 1,530. It has no municipal water supply and sewage systems. The water in the rock at Chilton generally stands from 30 to 75 feet below the surface. Wells in the drift strike water nearer the surface, and flow in a few cases.

In the Malt Company's two wells as already stated the water from the Trenton limestone rose to within 32 feet of the surface, but dropped to 75 feet below on entering the St. Peter sandstone, where it remained. The water is raised by means of an air compressor. The water is used for malting purposes, and contains only a normal amount of carbonate of calcium and magnesium, as indicated by the analyses.

The folowing material was passed through in drilling the deeper well:

Section of the Chilton Malting Co. well No. 2—Altitude of curb 877.

Formation.	Feet.
Pleistocene.	
Red clay	10
Light clay	18
Niagara.	
Limestone	170
Cincinnati.	
Blue and green shale	300
Galena-Platteville (Trenton).	
Limestone	225
St. Peter.	
Sandstone	47
Reported as Potsdam but probably Lower Magnesian (127 feet).	
Red shale	12
Red sandstone	5
Limestone	53
Blue shale	5
Limestone	22
Red marl	6
Limestone	6
Cherty limestone	6
Silicious material (quartzite)	12
Total depth	897

The silicious material at the bottom, reported as quartzite, may be only hard, compact sandstone.

Brillion.—The population of Brillion is 998. At Brillion flowing water is obtained from the gravel below the clay, from the drift, and from the Niagara limestone. A good supply is often found in the Niagara shell-rock only a few feet below the drift. Probably the water under

pressure in the gravel seam below the clay, and that in the shell-rock, have the same source. Most of the wells are from 50 to 150 feet deep, and are from the same water vein.

All wells interfere with one another, but the Chicago and Northwestern Railroad Company's well affects the others most. When pumped hard it lowers the head of all the others, and if the pumping continues long enough, stops the flow from all the wells near it. The railroad company's well is as low as the other wells, and water is allowed to escape as soon as the reservoir is full. Measurements on city wells, taken while the railroad tank was being filled, showed that before pumping began the water at the railroad well was flowing over the surface, through the trough, and all the wells in the vicinity were flowing. After one and one-half hours pumping the water in the railroad well was lowered two feet four inches, while in a well 50 feet south, and in one 350 feet south, the water had fallen an equal amount. After two and one-half hours of pumping the water in the railroad well had fallen three feet nine inches, while the other two wells were lowered the same amount. Further lowering in the reservoir had no effect upon the level in the other two wells, since the casing of the well that supplied the railroad reservoir was at this level and water had to rise to this height before it could flow into it. The 8-inch pipe supplied a full stream, but it did not flow quite as fast as the water was pumped out, several hours being required for the water to regain its original head.

Several of these flowing wells have not been properly cased and have since lost their flow. The considerable leakage from some of the wells has greatly increased the surface supply. In other cases part of the water rises to the surface outside of the casing and is a source of annoyance.

The source of the flowing water is from the gathering ground to the north and west of Brillion. Numerous springs are also found in this vicinity. East of Brillion similar wells are struck, but do not flow on account of the higher elevation of the land surface.

Forest Junction.—At Forest Junction the drift is very deep, being, in many places, over 200 feet thick. The water comes from quicksand and gravel. Here, too, are found several flowing wells from drift, and often gas is encountered in the drift. The pressure at the curb of some of the wells is as high as 22 pounds per square inch, and in one of the wells, it is reported, the gas was thrown up 50 feet and burned steadily for two days before the well was shut off. The gas comes from the seams below the clay, and very likely resulted from the decay of vegetable growth, since logs and twigs are often encountered in drilling wells. It is necessary to case through this gas vein and then water is obtained from quick-

sand below. Some oil has also been struck in these wells, but not as frequently as gas. Similar drift conditions are found at other points in the Fox river valley.

New Holstein.—The population is 839. The water supply is obtained from private wells 60 to 100 feet deep. Sewage is disposed of in open drains. The formation is clay loam over the Niagara limestone. The limestone appears at the surface in places, but usually it is covered with 30 to 40 feet of drift.

Hilbert.—The population is 572. The water supply is obtained from private wells 12 to 40 feet deep in drift overlying the limestone. Some of the wells are drilled to depth of 128 feet in the underlying limestone.

QUALITY OF THE WATER

The water of Calumet County, at least that obtained from the surface formations and the Niagara limestone, as shown in the following table is hard water of moderate mineral content. They are carbonate waters with calcium as the predominating constituent, and magnesium generally second in importance. Water from the deeper seated formations may, or may not, have a higher content of mineral matter.

The water of the flowing wells at Brillion, No. 1, contains 2.52 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Calumet County.

(Analyses in parts per million.)

	Surface Deposits.			Niagara limestone.	St. Peter sandstone.	
	1.	2.	3.	4.	5.	6.
Depth of well....feet..	120	25	52	254	740	897
Silica (SiO_2)....	15.4	20.7	....	undt.	20.	18.
Aluminum and iron oxides (Al_2O_3+Fe_2O_3)....	3.9				12.	8.
Calcium (Ca)....	64.2	56.3	55.6	55.4	67.9	48.7
Magnesium (Mg)....	33.4	36.5	44.2	44.8	13.9	41.7
Sodium and potassium (Na+K)....	6.4	29.0	19.4	22.2	22.8	14.
Carbonate radicle (CO_3)....	225.9	196.3	199.0	194.9	118.4	157.3
Sulphate radicle (SO_4)....	19.4	22.8	4.1	31.2	28.8	30.9
Chlorine (Cl)....	8.9	2.8	19.7	9.3	35.7	21.
Total dissolved solids....	377.	365.	342.	358.	319.	340.

1. Flowing well at Brillion. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Aug. 17, 1895.
2. Well of C. M. & St. P. Ry. Co., Hilbert Jct. Analyst, G. N. Prentiss, July 7, 1891.
3. Well of C. M. & St. P. Ry. Co., Hilbert Jct. Analyst, G. N. Prentiss, Mar. 7, 1900.
4. Well of C. M. & St. P. Ry. Co., Hilbert Jct. Analyst, G. N. Prentiss, Jan. 12, 1913.
5. Well No. 1 of Chilton Malting Co., Chilton.
6. Well No. 2 of Chilton Malting Co., Chilton.

Chippewa County

Chippewa County, located in the northwestern part of the state, has an area of 1,022 square miles, and a population of 32,103. About 58.4 per cent of the county is in farms, of which 50.5 per cent is under cultivation. The most thickly settled portion is the southwestern part, only a sparse population being in the northeastern part.

SURFACE FEATURES

The southwestern portion of the county, occupied by the Upper Cambrian (Potsdam) sandstone, has the hilly features characteristic of the sandstone outcrop. The thick drift covered portion of the county, the northeastern two-thirds, is an undulating plain. The belt of choppy

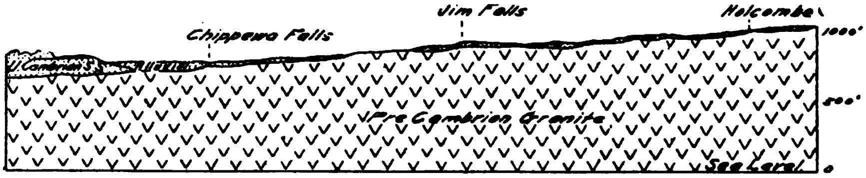

Fig. 25.—Geologic section along Chippewa river in Chippewa county.

moraine lies diagonally across the county, extending northwest and southeast, in the central part, crossing the Chippewa River at Jim Falls. Numerous picturesque lakes lie in the north central part. Altitudes generally range from 800 to 1,050 feet along the Chippewa River to 1,000 and 1,200 feet over the inter-valley areas. Flambeau Ridge, an isolated hard quartzite ridge in the northern part, reaches and altitude of about 1,500 feet. The soil is usually a sand loam along the Chippewa in the southern part, and silt loam in other parts of the county.

GEOLOGICAL FORMATIONS

The geological formations are the Pre-Cambrian crystalline rocks in the northeastern part, and along the Chippewa River, as far south as Chippewa Falls, and the Upper Cambrian (Potsdam) sandstone in the southern and western parts of the county. Glacial drift in thick ridges of terminal moraine extends across the northeast portion. Alluvial sand and gravel fills the valleys in the southwestern portion. The cross section (figure 25) parallel to the Chippewa River, illustrates the geological structure of the county.

The thickness of the surface formations of glacial drift in the morainic ridges, in the northeastern part, probably reaches 100 to 150 feet. The thickness of the extensive filling of sand and gravel probably reaches 200 to 250 feet in the deepest portions of the pre-glacial valleys. The thickness of the sandstone ranges between wide limits on account of the extensive erosion of the strata. The complete thickness of the sandstone is nowhere preserved within the county. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Chippewa County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250.
Upper Cambrian (Potsdam) sandstone	0 to 500.
The Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

The chief water-bearing horizons are the sandstone, the glacial drift and the alluvial formations. A small amount of water only can usually be obtained from the granite. The amount obtained is generally sufficient for farm purposes but is wholly inadequate for villages or city supplies. The small amount of water obtainable from the crystalline rock is well illustrated by a well 333 feet deep recently drilled in granite formation at Cornell. This well as shown by a test showed a production of only a little over 6 gallons per minute or a daily capacity of only 8,640 gallons. By continuous pumping for many days this production would undoubtedly be greatly reduced. It may therefore be considered as very impractical to attempt to obtain more than small amounts of water from the Pre-Cambrian crystalline formations.

Most of the wells in the county are relatively shallow, from 10 to 40 feet deep. On hilly land the wells are deeper, from 40 to 100 feet or more, depending upon elevation above the general level of the streams of the locality. Springs mainly occur only along the lowest portion of the Chippewa valley, where the sandstone formation, containing shaley strata, outcrops along the river bank, as illustrated by the well known Chippewa Mineral Spring at Chippewa Falls.

WATER SUPPLIES FOR CITIES AND VILLAGES

Chippewa Falls.—Chippewa Falls, situated on the site of extensive water power on the Chippewa river, has a population of 8,893. The city is located upon sandy, gravelly terraces of alluvial origin, which overlies the Upper Cambrian (Potsdam) sandstone and the Pre-Cambrian granite formations. The granite and sandstone formations are well exposed in Irvine Park.

Formerly the city water supply was derived from 36 six-inch driven wells, but this system was abandoned because of insufficient supply. At present the supply is derived from a sand and gravel bed lying along the Chippewa River about a mile above the city. The water level in this bed is 8 feet above the usual level of the river. Five steel cylinders, 5 feet in diameter, were sunk into this bed to a depth of 16 feet, probably to the granite. The water comes in from the bottom and from ¼ inch holes drilled into the cylinders. The capacity of the five wells is 2,000,000 gallons per day; the average daily consumption is about 500,000 gallons.

About 80 per cent of the houses are connected with the water system. Sewage is emptied, without purification, into the river. About 10 per cent of the families have cess pools. Private wells are from 10 to 100 feet deep in the gravel and sand, the depth depending upon elevation above the river.

Stanley.—This city, situated on the Wolf River, a small branch of the Eau Claire, has a population of 2,675. It is located on glacial drift. The Pre-Cambrian granite is generally struck at a depth of 60 to 80 feet. The sandstone overlies the granite in places attaining a thickness of 30 or 40 feet.

The city has a water supply system, which, until very recently, was used for fire service only. The city supply is obtained from two large wells 30 feet deep in the drift. The private wells average about 25 feet deep. Sewage is discharged, without purification, into the river. About 40 per cent of the houses have sewer and water connections. About 75 per cent of the families have cess pools.

The present city supply (1913) is reported to be inadequate and a new source is being investigated. A very good and sufficient supply should be obtainable from the sandstone underlying the surface drift.

Cadott,—Cadott, population 765, located on the Yellow River, has a water system for fire purposes only. Private wells in drift and crystalline rock are from 10 to 40 feet deep.

Boyd.—Boyd, population 527, situated on Hay Creek, has a water supply system for fire purposes. Private wells are from 20 to 40 feet deep generally. Sandstone underlies the drift in this locality.

Bloomer.—Bloomer, situated on Duncan Creek, has a population of 1,204. This place is located upon the sandstone formation. A city water supply has been installed. The private wells are generally from 10 to 40 feet deep. On the low ground about Bloomer, and on Eagle Prairie, wells are generally from 16 to 20 feet deep to water. The city supply is obtained from two wells, 130 and 207 feet deep.

QUALITY OF THE WATER

The water of Chippewa County is but slightly mineralized, as indicated by the available chemical analyses. The shallow depth of the water-bearing formations indicates that only slightly mineralized water, though somewhat higher in mineral content than that analyzed in the table, is likely to occur in most parts of the county.

The water of the well known Chippewa Mineral Spring at Chippewa Falls is very soft water. The analysis shows a content of only 36 total solids in 1,000,000 parts, and it is probably one of the softest, if not the softest spring water in the United States extensively placed upon the market. The city water supply at Chippewa Falls is also soft water. The water from the sandstone in the railroad well at Bloomer contains only 0.61 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Chippewa County.

(Analyses in parts per million.)

	Spring.	Surface deposits.	Upper Cambrian (Potsdam) sandstone.
	1.	2.	3.
Depth of well ... feet	......	16	169
Silica (SiO_2)	7.3	18.6	26.8
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)	......	0.8	5.5
Aluminum oxide (Al_2O_3)	.2	......	......
Iron (Fe)	.2	......	......
Calcium (Ca)	5.5	10.8	8.8
Magnesium (Mg)	2.2	4.9	5.0
Sodium (Na)	2.0	4.2	.8
Potassium (K)	.6		......
Carbonate radicle (CO_3)	15.0	28.3	24.0
Sulphate radicle (SO_4)	1.9	4.0	2.6
Chlorine (Cl)	.8	3.5	1.3
Phosphate radicle (PO_4)	.3	......	......
Organic matter	None.		
Total dissolved solids	36.	75.	75.

1. Chippewa Spring, Chippewa Falls. Analyst, Chas. W. Dreed.
2. City Supply, Chippewa Falls. Analyst, Dearborn Drug & Chemical Co., Jan. 16, 1908.
3. Well of C. & N. W. Ry. Co. at Bloomer. Analyst, G. M. Davidson, Aug. 29, 1910.

Clark County

Clark County, located in the north central part of the state, has an area of 1,200 square miles and a population of 30,074. Neillsville is the principal city with a population of 1,957. Prominent villages are Abbotsford, Greenwood, Loyal, Colby, Thorp, Withee, Dorchester, Humbird, and Owen. About 52.8 per cent of this county is laid out into farms of which 36.9 per cent is under cultivation.

SURFACE FEATURES

The topography depends upon the character of the underlying rock formation. The northeastern two-thirds of the county ocupied by thick drift over sandstone, is quite level. The southwestern part of the county, occupied by the very thin drift over sandstone, is characterized by hills of sandstone and broad level sandy valley bottoms and gentle slopes. Some of the highest sandstone mounds reach 150 to 200 feet above their immediate surroundings. The land gradually rises from an altitude of 900 feet in the southern part to over 1,200 feet in the northern part of the county. The difference in elevation between valley bottom and adjacent uplands is generally less than 100 feet.

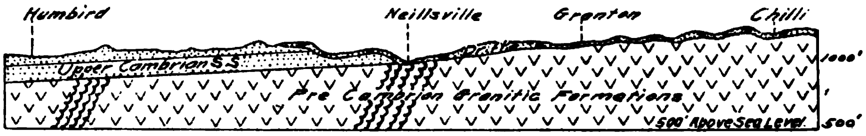

Fig. 26.—Geologic section, east-west, across southern Clark county.

GEOLOGICAL FORMATIONS

The geological formations are mainly the Upper Cambrian (Potsdam) sandstone, with the outcrop of the underlying crystalline rock exposed along the Black river, and in various places in the eastern part of the county. Glacial drift is abundant in the northern and northeastern parts of the county. Clay loam soil predominates over the thick drift covered portions, and sandy soils or sandy loams in the thin drift area in the southwestern part. The geological structure is illustrated in figure 26.

The thickness of the glacial drift probably does not exceed 200 feet. There appear to be no deep valleys of pre-glacial origin filled with alluvial sands and silts in this county. Hence, the surface formation is probably thickest in the old drift ridges. The sandstone occurs only as relatively thin remnants overlying the crystalline rocks in the northeast-

ern part of the county, and in somewhat thicker and more widespread areas in the southwestern part. The maximum range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Clark County.

Formation.	Thickness
	Feet.
Surface formation	0 to 200
Upper Cambrian (Potsdam) sandstone	0 to 200
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The ground water supplies are derived from the crystalline rock, from the sandstone and from the glacial and alluvial formations. Most of the wells in this county are shallow, usually less than 100 feet deep, but along the thick drift ridge east of Neillsville are a number of wells from 100 to 150 feet deep. The depth of the wells in eastern Clark County is shown on the map, Plate 50, in Wisconsin Survey Bulletin No. XVI.

WATER SUPPLIES FOR CITIES AND VILLAGES

Neillsville.—The source of the city water supply at Neillsville, population 1,957, formerly was a large open well on the bank of the Black river, 35 feet deep, 20 feet being in glacial drift and 15 feet in the underlying granite. At present the supply is obtained from the Black river at a depth of 20 feet. The average daily pumpage is 90,000 gallons. About 75 per cent of the houses connect with the city supply. A number of private wells in the city are from 75 to 100 feet deep in drift. The city sewage is emptied without treatment, into the Black river.

Abbottsford.—The deepest wells in Abbottsford, population 947, pass through 30 to 40 feet of glacial drift and about 40 feet of sandstone, striking granite at 80 to 85 feet. An abundant supply of good water for the city can be derived from the sandstone beds. In the southwest part of the village, at Paul Wooche's, is 34 feet of drift and 2 feet of sandstone. At another place on Main Street is 29 feet of drift and 1 foot of sandstone. The railroad water tank well is reported to be 85 feet deep, 40 feet of drift, 40 feet of sandstone, and 5 feet of granite at bottom.

Dorchester.—The deepest well in Dorchester reported is at Keen's Planing Mill, which is drilled 34 feet in drift and 6 feet in rock, probably granite. Most of the wells in this village are about 16 feet deep in drift.

Colby.—The population is 869. Most of the wells in Colby are shallow wells. In the northeastern part of the city, at the stave factory, is a well 101 feet deep in drift, striking hard granite at the bottom. The city supply recently installed is obtained from a 30-foot well.

Curtiss.—Most of the wells in Curtiss are shallow wells. At the sawmill is a well 107 feet deep, 100 feet in drift and 7 feet in rock, probably sandstone.

Loyal.—The population is 677. A public water supply was recently installed, the supply being obtained from one well 16 feet in diameter and 30 feet deep. The average daily pumpage is 19,000 gallons. About 40 houses connect with the city supply. Private wells in Loyal strike sandstone at variable depths, from 5 to 65 feet. At C. Ehlerts, half a mile east of the village, is a well 89 feet in drift. At the Lutheran Church is 84 feet of drift. The average depth to sandstone is said to be about 60 feet. An abundant supply of good water can be derived from the sandstone beds under the drift in Loyal.

Greenwood.—Along the Black river at Greenwood granite is exposed, but many of the wells in the village on higher ground strike sandstone at depth of 10 to 30 feet. In a few wells the drift rests directly on the granite. A good supply of water is derived from the sandstone. The known maximum thickness of sandstone is 32 feet. A city supply was recently installed, the supply being obtained from a well 30 feet deep.

Withee.—The village of Withee has a public water supply, recently installed. The supply is obtained from a well 140 feet deep, 80 feet in glacial drift and 60 feet in the underlying sandstone. The diameter of well is 12 inches in the drift and 5 inches in the sandstone. Casing extends to depth of 90 feet. The water level is about 25 feet below the surface. By pumping 16 gallons per minute the water is lowered to depth of 60 feet in 20 to 30 minutes, at which depth it remains stationary. Only a small proportion of the houses are connected with the system. Private wells are generally 35 to 40 feet deep, striking water at 25 feet in the drift.

Owen.—Owen, with a population of 745, is installing a water supply system (1912), and plans to have a groundwater supply. At present the city mains are filled with water from the river and is utilized for fire protection only. A partial sewage system is installed on Main Street, with connections with 15 or 20 houses. Wells strike sandstone in Owen at depth of 45 feet. Most of the wells are shallow, from 10 to 30 feet deep. The latest report states that the city supply is obtained from a well 30 feet deep.

Thorp.—The population of Thorp is 741. Sandstone is struck in two of the wells in Thorp, at depth of 8 and 22 feet. The city supply is derived from a large open well 12 feet in diameter and 30 feet deep, the

lower 15 feet being blasted out of the granite. The water in the city well is obtained from fissures in the granite and is under light pressure, the well overflowing through a one-inch pipe when not being pumped.

Granton.—Sandstone underlies the drift at Granton, with granite outcrops only along the valley bottom of O'Neill Creek. At F. W. Davis' place, below the hill, near Granton, the well is 16 feet deep in drift, but on the hill in the northeast corner of Section 2 is a well 60 feet deep, with 16 feet of sandstone at the bottom. At J. E. Lee's is a well 65 feet deep, 34 feet of drift, 6 feet of sandstone, and 25 feet of hard granite. At Nelson Marsh's place the well is 67 feet deep, 7 feet of drift and 60 feet of sandstone.

Chili.—In Chili wells are generally from 15 to 25 feet deep. Sandstone is struck after penetrating clayey drift at a depth of 18 to 22 feet, from which good supplies of water are obtained.

QUALITY OF THE WATER

Only three analyses of the water supplies of Clark County are available, namely those of the railroad wells at Lynn. The water from these wells is probably fairly representative of the quality of the groundwaters over the entire county. The average quality is apparently close to the dividing line betwen soft and hard waters and thus closely approximating the water of Lake Michigan. Analyses No. 1 is medium hard water, while No. 3 indicates soft water. The groundwaters of the county will probably very generally contain from 100 to 200 parts per million of mineral matter while the surface waters in the creeks and rivers will probably generally contain less than 100 parts per million of mineral matter.

Mineral analyses of water in Clark County.

(Analyses in parts per million.)

	Surface deposits.		
	1.	2.	3.
Depth of well ....feet..	18	38	14
Silica (SiO_2) / Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	Undet.	4.2	Undet.
Calcium (Ca)	37.1	27.0	23.3
Magnesium (Mg)	11.7	9.5	5.9
Sodium and potassium (Na+K)	17.0	13.0	16.4
Carbonate radicle (CO_3)	83.6	69.7	49.7
Sulphate radicle SO_4)	35.5	18.1	34.1
Chlorine (Cl)	Undet.	Undet.	Undet.
Total dissolved solids	185.	141.	129.

1. Railroad well, Lynn. 18' x 12'. Analyst, Chemist C. M. & St. P. Ry. Co., April 18, 1900.
2. Stockyard well, Lynn. Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 22, 1899.
3. Railroad well, Lynn. Analyst, Chemist C. M. & St. P. Ry. Co., Mar. 29, 1900.

Columbia County

Columbia County, located in the south central part of the state, has an area of 776 square miles, and a population of 31,129. About 94.5 per cent of the county is laid out in farms, of which 65 per cent is under cultivation.

SURFACE FEATURES

The surface of the county varies from undulating and hilly land to gently sloping upland plains. The area is drained by the Wisconsin, the Fox and the Rock river systems. The highest land, except the Baraboo Bluffs and Gibralter Bluff, is along the divide between the drainage flowing southeast to the Rock and that flowing west and northwest to the Wisconsin and Fox. The valley of the Wisconsin is broad and flat bottomed between the mouth of the Baraboo river and the Dells at Kilbourn city. Below the mouth of the Baraboo river the valley is relatively deep and narrow as far as Prairie du Sac. At Kilbourn City are the picturesque Dells of the Wisconsin river. At Portage is a canal, provided with locks, connecting the waters of the Wisconsin and Fox rivers.

The Wisconsin river at Prairie du Sac is 740 feet above sea level and below the dam at Kilbourn 815 feet above sea level. The Fox river at the Portage lock is 781 feet above sea level. The general altitude of the Crawfish river valley at Columbus is between 840 and 850 feet. The highest land along the divide in the central part of the county is usually between 1,100 and 1,150 feet. Gibralter Bluff west of Lodi reaches an altitude of 1,240 feet. The high quartzite range forming the east end of the Baraboo Bluffs in Caledonia reaches elevations of 1,200 to over 1,400 feet above sea level.

GEOLOGICAL FORMATIONS

The geological formations include the Pre-Cambrian quartzite, the Potsdam sandstone, the Lower Magnesian limestone, the St. Peter sandstone, and the Trenton limestone. The Pre-Cambrian quartzite forms the east end of the Baraboo bluffs in the town of Caledonia, in the western part of the county. The Upper Cambrian (Potsdam) sandstone forms the principal outcrops in the valley of the Wisconsin river. The Lower Magnesian limestone covers a large part of the southern and eastern portions of the county. The St. Peter sandstone and the Galena-

Platteville (Trenton) formations cover a small area in the southeastern and northeastern parts of the county. Glacial drift of variable thickness covers the entire county, and thick alluvial deposits occur in the valleys of the Wisconsin and other rivers. The geological structure is illustrated in Fig. 27.

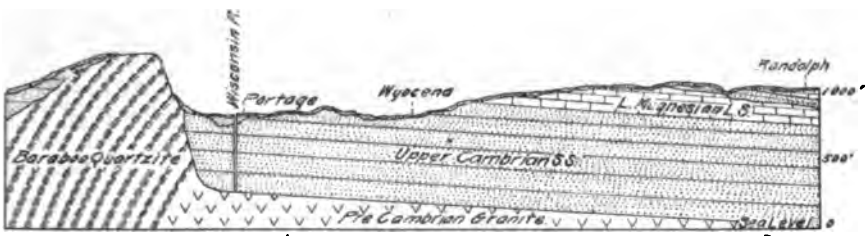

Fig. 27.—Geologic section, east-west, across Columbia county.

The thickness of the surface formation is variable, and probably attains a maximum of 300 to 350 feet in the old pre-glacial valleys. The thickness of the hard rock formations also varies greatly on account of the extensive erosion of the strata. The Pre-Cambrian crystalline floor lies at depth of 465 feet at Kilbourn and 550 feet at Portage. Its depth in the eastern part of the county is not known, but may be estimated at 800 or 900 feet at Columbus. The approximate range in thickness of the geological formations in the county, outside the area of the Baraboo quartzite bluffs, may be estimated as follows:

Approximate range in thickness of formations east of Baraboo bluffs in Columbia county.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena-Platteville (Trenton) limestone	0 to 100
St. Peter and Lower Magnesian formations	9 to 250
Upper Cambrian (Potsdam) sandstone	200 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the Upper Cambrian (Potsdam) sandstone, the glacial drift and alluvial deposits. In the eastern part of the county the Lower Magnesian limestone is important. The water level is usually less than 100 feet below the surface. On high isolated ridges in the western part of the county the wells are often 150 to 200 feet deep.

FLOWING WELLS

Artesian flows are known to occur only along the Crawfish river in the vicinity of Columbus, and in a tributary valley of the Wisconsin river at Lodi. At both these localities the flow is derived from sandstone strata in the upper portion of the Potsdam formation. The pressure is low, the water normally flowing a maximum of only 3 feet above the surface at Lodi, and about 13 feet above the surface at Columbus. The head at Lodi is at altitude of about 820 feet, and at Columbus, at 840 to 850 feet. (For further description of flowing wells see under Lodi and Columbus).

WATER SUPPLIES FOR CITIES AND VILLAGES

Portage.—This city, population 5,440, on the Wisconsin river, has a city water supply and general sewage system, the latter only recently installed. Probably not more than 10 or 20 per cent of the houses are now connected with the sewer system. About 80 per cent of the houses are connected with the water supply. The water supply is taken from the Wisconsin river, the processes used for purification not being wholly satisfactory. At one time a sand strainer was used, and later Cook points were laid in the sand of the bottom of the river, but without apparent success. At the present time a filter is used which apparently gives satisfactory results.

The following is the log of the Court House well in Portage as kept by the driller, elevation of curb—818.52 feet above sea level:

Section of the court house well at Portage.

Formation.	Thickness.
Alluvial formation.	Feet.
Clay and sand	40
Hard pan	1
Quicksand	82
Red clay	1
Quick sand	5
Upper Cambrian (Potsdam) sandstone.	
Shale rock	5
Hard pan	1
Caving sand	13
Hard sandstone	7
Open seam	1
Brown sandstone	37
White sandstone	25
Red sandstone	45
White sandstone	176
Red shale	44
Brown shale	6
Red shale	6
Blue shale	29
Hard blue shale	1
Granular shale	5
Crystalline rock.	
Quartz-porphyry	25
Total depth	555

The Eulberg Brothers Brewing Company well, elevation of curb 809 feet, is 470 feet deep in Potsdam sandstone, like the above.

The water supply for the city, as already stated, is taken from the Wisconsin river through three intakes at depth of 3 feet, and is not wholly satisfactory. The average daily pumpage is 487,000 gallons. Judging from the two wells in the sandstone, a good artesian system of water could easily be developed at Portage that would furnish an abundant supply of pure water for city purposes.

Columbus.—This city, population 2,523, located on the Crawfish river, has a water supply system and a sewage system. About 400 families use the city supply. The sewage, without treatment, is emptied into the river. Many of the families still have cess pools. The water supply is obtained from three wells cased to rock, 74, 89 and 197 feet deep, which strike the Potsdam sandstone at 13 feet, the water rising 3 feet above the surface and flowing at the rate of 41 gallons per minute. Two private artesian wells, those of John Freudell and August Alschwager, are reported 110 and 157 feet deep, having a flow of 13 feet above the surface. The water in 8 other wells, varying in depth from 56 to 192 feet rise up to, or very near the surface.

Artesian flows, similar to those at Columbus, are obtained farther to the northwest, in the vicinity of Fall river, and at other points about Columbus. To the east and northeast the wells obtain water chiefly from the Trenton limestone, and from the drift.

Kilbourn.—The population of Kilbourn is 1,170. The city supply of water for Kilbourn is obtained from five 8-inch wells, 100 to 150 feet deep in the Potsdam sandstone, and two large open wells 20 feet in diameter by 16 feet deep. The wells are about 150 feet apart and occupy the low ground along the creek bottom near the river. Two of the 8-inch wells are drilled into the bottom of the large open wells, and all the wells are connected so as to draw from one another when the open wells are drawn down below the general ground water level.

No sewage system is installed. About 75 per cent of the families use the city water. The private wells vary from 20 to 40 feet deep in the sandstone. A deep well* was drilled at this place in 1874 to a depth of 1,320 feet, striking the crystalline rock at 465 feet. The elevation of the curb is 928 feet above sea level; hence, the crystalline rock was struck at 463 feet above sea level.

Lodi.—The city of Lodi, population 1,074, obtains its water supply at present from a flowing well, 10 inches in diameter and 257 feet deep in drift and blue clay and the Potsdam sandstone formation. The

*Geology of Wis. Vol. II, pp. 50–51.

average daily pumpage is 40,000 gallons. About 75 per cent of the population use the city supply. The C. & N W. Ry. Co. well, elevation of curb 818 feet, flows 3 feet above the surface if valve is placed on the well casing so water may be shut off when not used. It is cased 175 feet. The well is allowed to flow only when pumps are running, and in this way no draft is made upon the underground reservoirs. If this precaution were always taken our reservoirs and artesian basins would be more serviceable. The water is hard, though of moderate mineral content (See table of analyses), and is used extensively for boilers, supplying daily about 60 locomotives.

Pardeeville.—This village, population 987, has no city water supply or sewage system. The wells vary in depth from 15 to 25 feet, the formation being 2 or 3 feet of surface loam and the rest sand or sand and gravel. Most of the wells are driven wells.

Cambria.—This village, population 657, has a water supply for fire protection only. Many of the private wells are from 40 to 100 feet deep, usually in the rock.

QUALITY OF THE WATER

The mineral content of the water is variable, depending upon the source of the supply. The Wisconsin river water is soft water; likewise that obtained from the city wells at Kilbourn. The water from the St. Peter sandstone and likewise that obtained from the Upper Cambrian (Potsdam) sandstone, is hard water. At Doylestown, within the area of limestone, overlying the sandstone, is very hard water with relatively high content of sulphates of calcium and magnesium. All the waters analyzed are carbonate waters.

The railroad well at Lodi, Analysis No. 23, contains 2.40 pounds of incrusting solids in 1,000 gallons, while the Wisconsin river water at Portage, Analysis 1, contains 0.64 pounds in 1,000 gallons.

Mineral analyses of water in Columbia County.

(Analyses in parts per million.)

	River.				Lake.	
	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	13.0					
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)		undet.	5.4	undet.	undet.	10.8
Aluminum oxide (Al_2O_3)						
Iron (Fe)	.2					
Calcium (Ca)	14.0	7.0	15.5	17.2	31.2	33.5
Magnesium (Mg)	6.8	2.9	7.2	6.0	22.6	13.6
Sodium and potassium (Na + K)	8.1	6.5	6.1	5.5	4.2	1.4
Carbonate radicle (CO_3)		22.9	48.0	42.6	101.0	82.7
Bicarbonate radicle (HCO_3)	58					
Sulphate radicle (SO_4)	17.0	5.2		3.5	4.9	2.1
Chlorine (Cl)	2.1		.7	4.0	4.1	2.1
Nitrate radicle (NO_3)	.9					
Suspended matter	4.6					
Total dissolved solids	98.	44.	83.	79.	168.	146.

	Surface deposits.			Upper Cambrian (Potsdam) sandstone.		
	7	8	9	10	11	12
Depth of well feet	17.	20.	30.	65.	74.	85.
Silica (SiO_2)				15.4		
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)	undet.	1.4	undet.			
Aluminum oxide (Al_2O_3)				2.5	.8	2.7
Iron (Fe)				.4		
Calcium (Ca)	96.0	70.6	14.7	65.2	63.9	65.5
Magnesium (Mg)	49.2	32.4	5.4	34.9	36.8	39.1
Sodium and potassium (Na + K)	15.7	14.5	7.2	8.2	4.4	3.0
Carbonate radicle (CO_3)	190.9	171.4	40.3	190.0	186.9	195.1
Sulphate radicle (SO_4)	124.3	49.1	2.5	6.4	8.2	4.6
Chlorine (Cl)	21.5	2.0	2.8	1.9	.8	1.3
Total dissolved solids	498.6	341.	73.	325.	302.	311.

1. Wisconsin river, near Portage. Mean of 24 analyses. U. S. Geol. Survey, W. S. P. No. 236, p. 113, 1906–7.
2. Wisconsin river. City water works, Portage. Analyst, G. N. Prentiss, Nov. 8, 1900.
3. Wisconsin river. City Water Works, Portage. Analyst, G. N. Prentiss, Mar. 16, 1891.
4. Wisconsin river. City Water Works, Portage. Analyst, G. N. Prentiss, Dec. 12, 1903.
5. Silver Lake, Portage. Analyst, G. N. Prentiss, Dec. 12, 1903.
6. Silver Lake, Portage. Analyst, G. N. Prentiss, Feb. 3, 1888.
7. Well of C. M. & St. P. Ry. Co., Poynette. Analyst, G. N. Prentiss, Dec. 12, 1902.
8. Well of C. M. & St. P. Ry. Co., Clipnogen side track, Sect. 4, T. 12, R. 11. Analyst, G. N. Prentiss, Sept. 10, 1889.
9. Well of City Water Supply, Kilbourn City. Analyst, G. N. Prentiss, Nov. 4, 1903.
10. Well of J. C. Brill, Columbus. Analyst, G. Bode.
11. City well at Columbus. Analyst, H. E. Smith.
12. Railroad well at Columbus. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 16, 1891.

Mineral analyses of water in Columbia County—Continued.

	Upper Cambrian (Potsdam) sandstone.				
	13.	14.	15.	16.	17.
Depth of well ... feet	90	75	55	60	168
Silica (SiO_2) / Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	2.1	.8	2.7	undet.	undet.
Calcium (Ca)	62.8	63.9	65.6	47.6	49.0
Magnesium (Mg)	36.9	37.2	39.4	26.9	26.7
Sodium and potassium (Na+K)	2.1	4.5	6.5	3.2	6.4
Carbonate radicle (CO_3)	178.3	187.1	199.6	131.3	115.3
Sulphate radicle (SO_4)	12.7	83[illegible]	4.6	4.1	25.5
Chlorine (Cl)	1.8	.8	1.4	8.1	9.1
Nitrate radicle (NO_3)	....	....	....	....	15.7
Total dissolved solids	297.	302.	320.	221.	248.

	Upper Cambrian (Potsdam) sandstone.					
	18.	19.	20.	21.	22.	23.
Depth ... feet	140	46	135	310	325	212
Silica (SiO_2) / Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	undet.	undet.	....	....	....	15.9 / 1.0
Aluminium oxide (Al_2O_3)	....	....	1.2	1.0	1.7	....
Calcium (Ca)	11.2	54.9	28.6	97.3	97.4	60.2
Magnesium (Mg)	4.0	30.4	16.8	52.4	51.7	33.7
Sodium and potassium (Na+K)	8.6	10.9	13.8	9.2	13.9	5.8
Carbonate radicle (CO_3)	33.9	156.1	58.6	205.5	210.5	169.5
Sulphate radicle (SO_4)	2.0	8.6	6.0	112.4	111.4	6.4
Chlorine (Cl)	3.0	11.0	47.3	14.2	14.3	8.9
Total dissolved solids	63.	272	172.	492.	501.	301.

13. Well of C. M. & St. P. Ry. Co., Columbus. Analyst, G. N. Prentiss, Mar. 16, 1899.
14. City well, Columbus. Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 2, 1896.
15. Well of C. M. & St. P. Ry. Co., Columbus. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 30, 1890.
16. Well at stock yards, Poynette. Analyst, G. N. Prentiss, Dec. 7, 1905.
17. Well at stock yards, Arlington. Analyst, G. N. Prentiss, Mar. 28, 1907.
18. Well at Kilbourn City, open well 80 ft. by 6 ft. drilled 60 ft. by 6 in. Analyst, G. N. Prentiss, Nov. 4, 1903.
19. Well of Louis Sevenson, East Rio. Analyst, G. N. Prentiss, Mar. 15, 1906.
20. Railroad well at Kilbourn City. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 15, 1890.
21. Private well at Doylestown. Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 16, 1899.
22. Railroad well at Doylestown. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 15, 1890.
23. Well of C. & N. W. Ry. Co., Lodi. Analyst, G. M. Davidson, Oct. 6, 1896.

CRAWFORD COUNTY

Crawford County, located in the southwestern part of the state has an area of 557 square miles, and a population of 16,288. About 92.6 per cent of the county is in farms, of which 44.8 per cent is under cultivation.

SURFACE FEATURES

The surface of Crawford County is a dissected upland plain, characterized by deep and narrow valleys and long upland slopes with nearly level summit ridges. The Mississippi river on the western border, and the Wisconsin river on the southern border, lie in flat-bottomed valleys with precipitous valley sides or bluffs rising 300 to 400 feet above the river. The Kickapoo valley in the eastern part of the county has a nar-

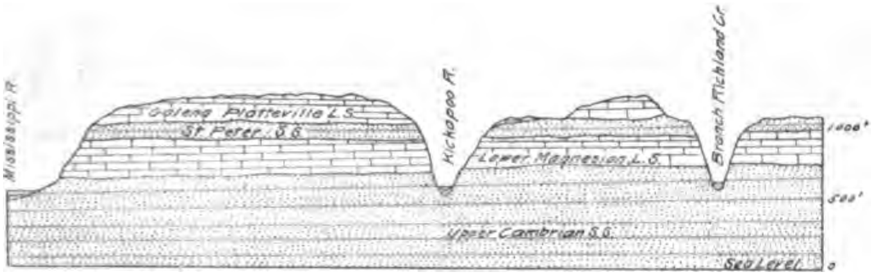

Fig. 28.—Geologic section, east-west, across southern Crawford county.

row bottom, generally less than one mile wide and from 300 to 400 feet below the general level of the uplands. The altitudes along the Wisconsin and Mississippi bottoms are generally between 620 and 640 feet, while that along the Kickapoo ranges from 640 at Wauzeka to 740 at Soldiers Grove. The highest uplands, a few miles from the rivers, reach altitudes of 1,200 to 1,300 feet above sea level.

GEOLOGICAL FORMATIONS

The geological formations of this county are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, the St. Peter sandstone, and the Galena-Platteville (Trenton) limestone. The Upper Cambrian (Potsdam) sandstone occurs only along the lower slopes of the

principal valleys, such as the Mississippi, the Wisconsin and the Kickapoo rivers. The Lower Magnesian limestone is the formation of most common outcrop. The area of the Platteville and Galena formations, (Trenton) is mainly west of the Kickapoo river. The geological structure is illustrated in Fig. 28.

In the valleys is a thick deposit of alluvial sand and gravel, probably attaining a thickness of 200 to 300 feet, and upon the uplands is a variable amount of loess, usually from 1 to 5 feet thick, overlying the bed rock. The rock formations vary in thickness on account of the extensive erosion of the strata It is only where a formation is protected by the next overlying formation that the complete thickness is preserved. The maximum range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Crawford County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Galena-Platteville (Trenton) limestone	0 to 150
St. Peter and Lower Magnesian formations	0 to 250
Upper Cambrian (Potsdam) sandstone	500 to 1,000
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the Upper Cambrian sandstone, the Lower Magnesian limestone and the St. Peter sandstone. The alluvial sand is a common source of water in shallow wells in the valleys. The depth to water level is generally from 10 to 40 feet in the valleys and from 100 to 400 feet on the uplands.

Near Steuben, in the eastern part of the county, several of these wells are from 350 to 400 feet in depth, with only a few feet of water in them. The great depth of the water table in the hilly uplands is due to the steep slopes, from which the water readily drains into the valleys. At A. Kopon's farm 3 miles south of Steuben, Sec. 19, T. 8 No., R. 4 W., a well is drilled on a hill to a depth of 374 feet. The water was struck at 355 feet in limestone (Lower Magnesian) and must be pumped from 345 feet, the water in the well being only 29 feet deep. The well is cased 158 feet, but rock was struck 12 feet below the surface.

FLOWING WELLS

Flowing wells are common along the valley bottoms of the Mississippi and the Wisconsin, and also up many of the side valleys leading from these main streams. Most if not all the flowing artesian wells get their supply from the Upper Cambrian sandstone. At least five water horizons are found in the Upper Cambrian at Prairie du Chien. Most of the wells range in depth between 30 to 1,000 feet. In Prairie du Chien there are four deep flowing wells and 30 or 40 flowing wells ranging in depth between 350 and 400 feet.

One of the first, if not the first, artesian well[1] in Prairie du Chien, was drilled in 1875-76, depth 959 feet, diameter 5⅝ inches. The water in this well, when first drilled rose about 100 feet above the level of the Mississippi river, having a pressure of 40 pounds per inch, and a daily flowage of 869,916 gallons.

Along the Wisconsin river valley flowing wells from the Potsdam horizon may be had all the way from Wauzeka to Prairie du Chien. Along the Kickapoo river, north of Wauzeka, within Crawford County water is pumped from shallow wells, but there is no reason why flows should not be obtained in the lower part of the valley, south of Barnum, as well as at such places as Rockton and Ontario, at the upper end of the valley. The distribution of the flowing artesian wells in the Kickapoo valley and the probable explanation of the absence of flowing wells between Soldiers Grove and Barnum is given on pages 71–2.

Additional data concerning flowing wells are referred to on the following pages.

WATER SUPPLIES FOR CITIES AND VILLAGES

Prairie du Chien.—This city, having a population of 3,149, is situated at the junction of the Wisconsin and Mississippi rivers. Prairie du Chien was one of the first cities in the state to have a public water supply, mainly because of the occurrence of strong artesian flows. The wells developed sufficient pressure for a direct pressure system like that later developed at De Pere. This supply was in use for many years until the pressure decreased so much that it would no longer supply the demands. At present the water supply is principally from private wells. Recently the city has developed a groundwater supply, drawn from an open dug well in alluvial sand, 30 feet deep, into the bottom of which are driven 4-inch well points 8 feet long. Only about 10 per cent of

[1]Geol. of Wis., Vol. IV, p. 61.

the families use the city water. The city sewers empty into the Mississippi river. About 25 per cent of the families have cess pools. Although pure artesian water may be obtained, there are many shallow wells in use from 10 to 30 feet in depth. Even the city supply, as above stated, is drawn from an open well only 30 feet deep. Since this formation is a sandy alluvial deposit, an old river bar, or filled bank, there is nothing to prevent the well water from being contaminated at any time. A much better, and certainly as cheap a supply might have been derived from the sandstone formation, with much safer water and nearly as free from iron.

All the artesian wells get their supply from the Upper Cambrian (Potsdam) sandstone and none have struck crystalline rock. At least five good water horizons are found in the sandstone at Prairie du Chien, and possibly more, since no detailed record is available below 990 feet. Mr. Winnegar, however, stated that the flow continued to increase between 1,000 and 1,044 feet, clearly showing that there is at least one more water vein below 990 feet.

Flowing wells in Prairie du Chien.

Owner.	When drilled.	Depth, feet.	Dia. of casing, inches.	Length of casing, feet.	In 1903 Head above surface feet.	In 1903 Flow per minute, gallons.	Temperature, F°
Stock Company	1876	960	6-4½	148	18	?	57
F. L. Winnegar	1878	1,017	6	118	60	540	57
F. L. Winnegar	1878	1,044	8	115	60	540	57
F. L. Winnegar	1884	500	8	115	30	20	54
Sanitarium	1903	990	6	147	24	150	57
I. B. Brunsen	1879	375	4	135	25	97	54
T. L. Bower	1880	350	4	132	29	160	54
C. M. & St. P. Ry. Co.	1880	371	4	120	41	192	54
H. L. Dousman	1882	374	4	116	43	218	54
H. L. Dousman	1881	365	4	....	12	....	....

In order to show the relations of the various beds the section of the new well at the Sanitarium is given.[1] A set of samples of the new well may be seen in the Geological Museum at the University of Wisconsin.

[1] For description of the old well see Geology of Wisconsin, Vol. IV, p. 61.

Section of sanitarium artesian well, Prairie du Chien. Altitude 653.

Formation.	Depth.	Thickness.	Remarks.
Alluvium.	Feet.	Feet.	
Fine surface sand	0 - 55	55	
Coarse river-washed sand	55 147	92	
Upper Cambrian (Potsdam)			
Hard cherty limestone (Mendota)	147-152	5	
Greenish sandy shale	152 -273	121	
Coarse sandstone,	273-290	17	Water rises to surface and supplies most of the wells.
Fine white sandstone	290-449	159	No water.
Gray greenish shale	449-500	51	
Sticky red clay	500-515	15	
Bluish green sandy shale	515- 560	45	
Bluish green sandstone	560-620	60	Strong flow.
Coarse bluish green sandstone	620 720	100	Dry.
Very coarse yellow sandstone	720 805	85	Much water.
Red clay	805-806	1	
Fine pinkish white sandstone	806--945	139	Water vein.
Yellowish white sandstone	945-990	45	Much water.
Blue shale	....	....	
Total depth	....	990	

The iron and saline properties of the waters corrode iron pipes so rapidly that it was found necessary to line them with copper. It is also stated that the copper lining in the old city well did not extend quite to the bottom of the iron casing and a slight leak may occur at this place. Proper tests at the well would soon prove this. The water from the old city well has been used at the Sanitarium, but a new well drilled at the new Sanitarium furnishes practically the same kind of water.

The two wells at Mr. Winnegar's mill are used for water power. The pipes corroded in two years and new pipes with copper lining were put in, which have remained until the present time. These wells are on the lowest ground in the city and will stop the flow of other wells in the city if opened and allowed to run at their full capacity.

The two wells at Winnegar's mill have a capacity of 144 cubic feet per minute and approximately force enough for a 30-foot head. About 8-horse power is developed. A 10-inch turbine wheel was put in in 1878, and has been doing the grinding at the mill ever since. In 1894 auxiliary steam power was added. This however, is used only during the busy season. The third well, a 500 foot well, is not used at present.

It seems most probable that the decrease in the old Stock Company well is largely due to the Winnegar wells, for the head in the new Sanitarium well is approximately the same as the wells at Winnegar's mill, while the first city well, is somewhat less, due partly to 5 feet of filling and to leakage at the place where the copper lining did not cover the iron casing. If the wells at the mill are allowed to flow freely the well

at the courthouse will stop flowing in about 3 hours. There are several wells 300 to 400 feet deep, as at the C. M. & St. P. R. R. Stock Yards, which are more or less neglected and allow water to escape at lower levels tending to reduce the head. It appears that in the deep wells, the head has decreased about 20 feet, while in the shallower wells it has not diminished and in some cases has increased. In some wells, however, the flow has stopped entirely, owing to neglect. It, therefore, seems probable that as more deep wells penetrate the lower horizons water may escape into the higher horizons which have a lower head, and thus decrease the head in the lower horizons, but increase the heads in the upper horizons. After enough holes have been drilled the heads from the lower and the upper horizons will be approximately the same. To avoid loss in the various flows this leakage from the lower horizon ought to be confined to their respective horizons by means of proper casing. The deeper waters contain much more iron than the shallow waters, and also much more saline mineral matter.

Prairie du Chien to De Soto.—North of Prairie du Chien, along the Mississippi river, wells much like those at Prairie du Chien are obtained, and therefore no detailed record of each well is necessary. Although none of the wells at Prairie du Chien, and in Crawford County, have struck granite, those farther north frequently penetrate through the sandstone and reach the granite.

Wauzeka.—Mr. Steisel's well is at the highest point in the village but gives a fine flow.

Section of A. W. Steisel's well at Wauzeka.

Formation.	Thickness.	Remarks.
Alluvial.	Feet.	
Sand	24	
Upper Cambrian (Potsdam)		
Shale, blue	151	
Sandstone, white	100	Water rose 1½ feet in this sand.
Sandstone, blue	150	At 300 feet dropped 6 feet.
Sandstone, white	175	At 470 feet stood at ½ feet.
Total depth	600	At 600 feet a strong flow.

The water in all the wells at Wauzeka comes from the Upper Cambrian sandstone. In some of the wells crevices occur in the upper part of the formation, and in order to maintain a flow wells must be packed at proper places and kept in repair. Some of the wells have been repacked several times and are as strong today as ever. These fissures may account for the lower head from the upper part of the horizon.

Soldiers Grove.—This village, with a population of 667, has a public water supply obtained from an 8-inch well, 250 feet deep. The daily pumpage of water is about 5,000 gallons, about one-third of the houses being connected with the water supply. The average depth of the private wells is about 40 feet.

Gays Mills.—The village well is an 8-inch well 202 feet deep. The supply is mainly used for fire protection. The private wells are generally from 30 to 40 feet deep.

QUALITY OF WATER

The mineral content of the waters of Crawford County are fairly well shown in the table of analyses. The waters from the sandy alluvial deposits along the Mississippi, Wisconsin and Kickapoo rivers are likely to be somewhat lower in mineral content than the waters obtained from the sandstone as illustrated by the old railroad well at Lowertown. The water from the upper horizons of the Upper Cambrian sandstone is likely to be hard water of only moderate mineral content. The waters from one of the beds in the middle horizons of the sandstone is of a salty character at Prairie du Chien, as shown in analysis No. 5 of the deep artesian well.

At McGregor[1], Iowa, on the west side of the Mississippi River opposite Prairie du Chien, salt water was struck at a depth of a little over 520 feet below the surface, the total depth of the well being 1,006 feet. This deep well contained 2,789 parts per million of mineral matter, while a well only 520 feet deep at McGregor contains only 495 parts per million.

The salt[2] water of the artesian well at Prairie du Chien, analyses No. 5, was obtained at depth of 514 feet.

The source of the salt water at Prairie du Chien and McGregor is very apparently the same bed in the sandstone formation. The salt water occurs only in a restricted area, as it is not encountered in deep wells farther east in Wisconsin or farther west in Iowa, which penetrate the same strata.

While the source of the salt water at Prairie du Chien is very apparently a water-bearing stratum at depth of about 514 feet, the escape of the salt water from this depth into the upper horizons through the numerous deep wells that are now abandoned or are improperly cased has polluted the fresh water supplies in the upper horizons. This is shown by the fact that many of the shallow wells at the present time contain salt water.

[1]Iowa Geological Survey, Vol. XXI, p. 352.
[2]Geol. of Wis., Vol. IV, p. 61.

Mineral analyses of water in Crawford County.

(Analyses in parts per million.)

	Alluvial sand.	Upper Cambrian (Potsdam) sandstone.			
	1	2	3	4	5
Depth of well.......feet..	30	300	371	203	960
Silica (SiO_2)...... Aluminium and iron oxides. ($Al_2O_3+Fe_2O_3$)	1.2	2.4	2.0	Undt.	65.1
Aluminium oxide (Al_2O_3)......	....	....	....	....	1.0
Iron (Fe)......	....	....	....	....	1.2
Calcium (Ca)......	44.5	53.2	57.6	44.6	79.9
Magnesium (Mg)......	14.4	33.0	26.2	19.6	54.6
Sodium (Na)...... Potassium (K)......	17.7	4.0	39.9	29.1	677.9 34.0
Carbonate radicle (CO_3)......	84.4	161.7	151.2	136.8	140.8
Sulphate radicle (SO_4)......	52.7	7.1	29.0	19.6	333.4
Chlorine (Cl)......	8.3	0.9	40.1	4.1	967.1
Total dissolved solids......	223.	262.	346.	254.	2352.

1. Well of C. M. & St. P. Ry. Co., Lowertown, Prairie du Chien. Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 3, 1890.
2. Well of C. M. & St. P. Ry. Co., Wauzeka, flowing well. Analyst, Chemist C. M. & St. P. Ry. Co., May 29, 1890.
3. Well of C. M. & St. P. Ry. Co., Prairie du Chien, flowing well. Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 26, 1894.
4. Village well, Gays Mills. Analyst, Chemist C. M. & St. P. Ry. Co., Dec. 7, 1907.
5. Park well of Stock Company at Prairie du Chien. Analyst, G. Bode, prior to 1873.

Dane County

Dane County, located in the southern part of the state, has an area of 1,188 square miles, and a population of 77,435. About 95.7 per cent of the county is in farms of which 72.5 per cent is under cultivation.

SURFACE FEATURES

The surface is an undulating plain with gently sloping hills and broad valleys in the central and eastern part where glaciated, and relatively rough topography with narrow valleys and abrupt slopes in the western part where unglaciated. Most of the county is drained by streams flowing southeastward to the Rock river, only the northwestern one-fourth being drained by streams flowing west to the Wisconsin.

The most conspicuous elevation is the Blue Mounds on the western boundary, the highest point in southern Wisconsin, reaching an elevation of approximately 1,700 feet above the sea level, being about 500 feet above the general level of the summit of the surrounding upland area,

and nearly 1,000 feet above the Wisconsin river ten miles to the north. The uplands in the northeastern part of the county reach in general a maximum altitude of 1,000 feet and in the southeastern part about 1,100 feet, while those in the western part reach up to 1,200 feet. The general altitude of the valley bottoms in the eastern part ranges from 800 to 860 feet, the altitude of the lakes in the Yahara valley being as follows: Lake Kegonsa, 824; Lake Waubesa, 844; Lake Monona, 845 and Lake Mendota, 849. The valley bottom along the Wisconsin river on the northwest boundary of the county reaches an altitude of only about 740 feet, about 60 to 100 feet lower than the lowest valley bottom in the eastern

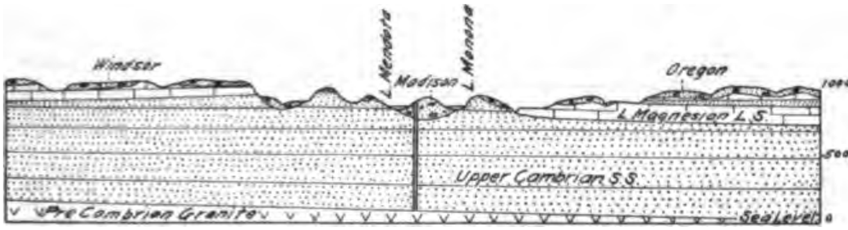

Fig. 29.—Geologic section, north-south, across Dane county.

part. The difference in altitude between valley bottom and adjacent upland ridge in the eastern part is usually therefore less than 200 or 250 feet, while in the western part the difference in elevation is often over 400 or 450 feet.

GEOLOGICAL FORMATIONS

The geological formations outcropping in the county (see map) are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, the St. Peter sandstone and the Platteville and Galena limestones. The northeastern part of the county, east of Cross Plains, Verona and Brooklyn, is covered with glacial drift. In the Blue Mounds the overlying formations of Cincinnati shale and Niagara limestone are represented. A belt of terminal moraine marks the border of the glaciated area. The southwestern part is driftless. The geological structure is illustrated in fig. 29.

The thickness of the surface formation of glacial drift varies greatly on account of the very uneven surface upon which it is deposited, and on account of inequalities in the accumulation of drift in ridges and depressions through the direct work of glacial deposition. Along the line of the Yahara valley the thickness of the drift is from 200 to 300 feet,

the surface of the bed rock in the old pre-glacial valley being about 250 feet below the present level of the Yahara.

The thickness of the rock formations is also variable between wide limits on account of the extensive erosion of the strata. The complete thickness of any formation is preserved only where protected by an overlying formation. The Pre-Cambrian granite floor at Madison lies at a depth of about 740 feet below the level of Lake Mendota, which is about 500 feet below the bottom of the pre-glacial valley of the Yahara. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Dane County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Niagara limestone (only in Blue Mounds)	0 to 200
Cincinnati shale (only in Blue Mounds)	0 to 200
Galena-Platteville (Trenton) limestone	0 to 300
St. Peter and Lower Magnesian formation	0 to 250
Upper Cambrian (Potsdam) sandstone	500 to 850
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

All the geological formations are drawn upon for water supplies, but the principal water-bearing horizons are the Upper Cambrian sandstone and the surface gravels and sands. The St. Peter sandstone and the Lower Magnesian limestone, and the Galena-Platteville limestone, are important sources for domestic and farm supply within the area of these formations. The water level is near the surface in the valley bottoms and on the lower slopes of the uplands, and at various depths below the surface on the hills and uplands, depending on the elevation above the adjacent valleys. In general the water level is usually less than 100 feet below the surface in the eastern part, but in the western part, where the hills rise higher above the level of the running streams, many wells reach depths of 200 to 300 feet to obtain a sufficient supply.

Shaly strata, or other relatively impervious formation within the rock formations, strongly influence the underground water levels, and tend to hold up the water relatively high in the hills. This condition is illustrated by the city well at Mt. Horeb, the altitude of the curb being 1,200 feet, the water being obtained from the St. Peter sandstone underlying the Galena-Platteville limestone, the water standing at depth of only 90 feet below the surface.

FLOWING WELLS

Flowing wells occur in both the surface deposits and the underlying rock in Dane County, but are unimportant as sources of water supply.

Surface flowing wells furnish the city water supply of the village of Mazomanie, the source of the supply being the gravel beds underlying clay.

Deep seated flows from the Upper Cambrian (Potsdam) sandstone were developed in Madison and Stoughton when the city wells were first drilled, but the initial head was sufficient to yield only a small supply. When city well No. 1 was drilled in Madison in 1882, there was sufficient pressure to raise the water in the well 4½ feet above the surface of Lake Mendota, to an altitude of about 853 feet. The artesian head though not high enough to develop flows above the surface reaches higher as the land surface rises, and the distance from the lake and Yahara river increases, as shown by the head of 12 feet above the lake level at the Slichter cottage on the north shore of Mendota, and the head of 16 feet above the lake level at the State Capitol. The new city well in Stoughton, altitude of curb about 842 feet, drilled in 1910, when completed flowed at the rate of only 10 gallons per minute.

SPRINGS

Springs are quite common in Dane County on the lower slopes of the valleys. A state fish hatchery is located at the site of a small group of springs four miles south of Madison. These springs issue from the drift. One near Mt. Horeb is used to run an electric light plant. Several springs, including the Merrill and the Livesey springs, are located on the west shore of Lake Mendota. The Bryant Mineral Spring near Madison supplies a large demand for spring water in the local market. The Keyes spring is located on the east side of Lake Monona. Other springs occur on many of the small streams that flow into the Yahara lakes, and along Black Earth Creek. The White Cross spring also supplies the local Madison market.

WATER SUPPLIES FOR CITIES AND VILLAGES

Madison.—This city, having a population of 25,531, the capital of the state, has a water supply and sewage system. The sewage is treated by a system of septic tanks and trickling filter, and empties into the Yahara river. About 84 per cent of the houses are connected with the sewage system. About 86 per cent of the houses are connected with the water supply system. The private wells are few, usually being from 20 to 40 feet

deep in sandy and gravelly drift. The use of these surface wells is objectionable, as the water is in much danger of contamination.

The water supply system at Madison has had an interesting growth, and as it represents the various stages of development, with the difficulties usually encountered in pumping large quantities of water from artesian sources, a brief review may throw considerable light upon underground water supply conditions elsewhere. Madison, at present, has probably the best developed artesian supply in Wisconsin, with an available daily capacity, as the pumps are now placed, of about 5,000,000 gallons. Under the present power development, however, as reported by City Engineer Icke in 1912, the daily pumpage capacity was about 3,000,000 gallons. A total of 535 hydrants are now in use (Feb. 1914). The approximate average daily consumption in 1910 and 1911 was 1,800,000 gallons, the consumption during some of the summer months closely approximating the pumpage capacity. A greater amount of water for city purposes, over 700,000,000 gallons, annually, is pumped for artesian wells only by Rockford, Illinois, where the shaft and tunnel system are in use.

In 1913, 776,157,750 gallons of water were pumped, an increase of 61,220,650 gallons over the preceding year. The average daily pumpage, in 1913, was 2,126,000 gallons and the cost was five cents per 100 gallons. In the summer of 1914, the usual daily pumpage was 2,500,000 to 3,000,000 gallons.

In 1881, when Madison decided to put in a system of waterworks, two artesian wells had been drilled in the city, one at the capitol, and the other at the Chicago, Milwaukee and St. Paul Railway station at West Madison, so that the underground conditions were fairly well known. See the geologic section, Fig. 30, illustrating character of the strata in the Madison city wells.

Sections of wells at Madison.

	Drift.	Upper Cambrian (Potsdam) sandstone.	Archean crystalline.	Total depth.
Capitol Park	126	679½	209½	1.015
C.M.& St.P.Ry.Co.	75	715	5	795
City well No. 4	105	645	....	750

The first city well, No. 1, was drilled in 1882 on the present waterworks block, 6 inches in diameter and 751 feet deep to granite. The well was full of water all the time, and when completed the water rose 4½

feet above the surface of Lake Mendota. The same year, another 6-inch well, No. 2, was drilled 55 feet northeast of the first and to the same depth. Well No. 2 seemed to interfere with No. 1, but the amount was not determined. A third well, No. 3, was then drilled in 1883, 55 feet north of east from the second well, and upon completion the total capacity of the three wells was about 600 gallons per minute, and the three wells furnished, per well, only 4/7 of the amount furnished by the first well. Another well, No. 4, was then drilled in 1883, 8 inches in diameter, 77 feet northeast of well No. 2. This well interfered with the well in the Capitol grounds 2,063 feet away, where the pumps had to be lowered 5 feet. As the supply was still insufficient in 1885 another 8-inch well, No. 5, was drilled 1,225 feet northeast from the third. On the advice of experts another 8-inch well, No. 6, was drilled in 1885, 700 feet east of well No. 3, and 700 feet south of well No. 5. This new well interfered with the flow of well No. 5, and only netted a gain of 80,000 gallons per day. By this time it was learned that the flow of the underground water furnishing the supply was moving from north to south, so the next step was to sink two wells in 1886, No. 7 and No. 8, only 226 feet deep, and drawing water through a depth of only 8 feet, the remaining 218 feet being shut off by casing. Each of these wells gave 80,000 gallons per day.

At this time it was discovered that the laterals supplying the wells with water, fed from within a radius of about 400 or 500 feet. In drilling the next two wells in 1894 this information was made use of with remarkable results. The ninth well, No. 9, 10 inches in diameter, and 821 feet deep, was located 1,050 feet east of well No. 5 and 2,275 feet from the pumps. In a 48-hour test of this well the water receded to 18 feet from the surface, where it remained stationary and showed a capacity of 589,040 gallons of water in 24 hours. The tenth well, No. 10, 10 inches in diameter, was located directly east of well No. 9 at a distance of 1,235 feet, or 3,500 feet in direct line from the pumping station. This well, with the same test as well No. 9, showed the same capacity. Well No. 11, located on Patterson St., 15 inches in diameter, and 760 feet deep, was drilled in 1909.

It will be noticed that each of the last two wells supplied about 390 gallons per minute more than the first well, which indicates that at the same head no marked interference resulted at this distance. The extraordinary dry season of 1901 conclusively proved the need for more water. To increase the yield of the present well system two methods were possible,—one to pump the water from a greater depth in the wells, the other to sink more wells at a considerable distance from those in opera-

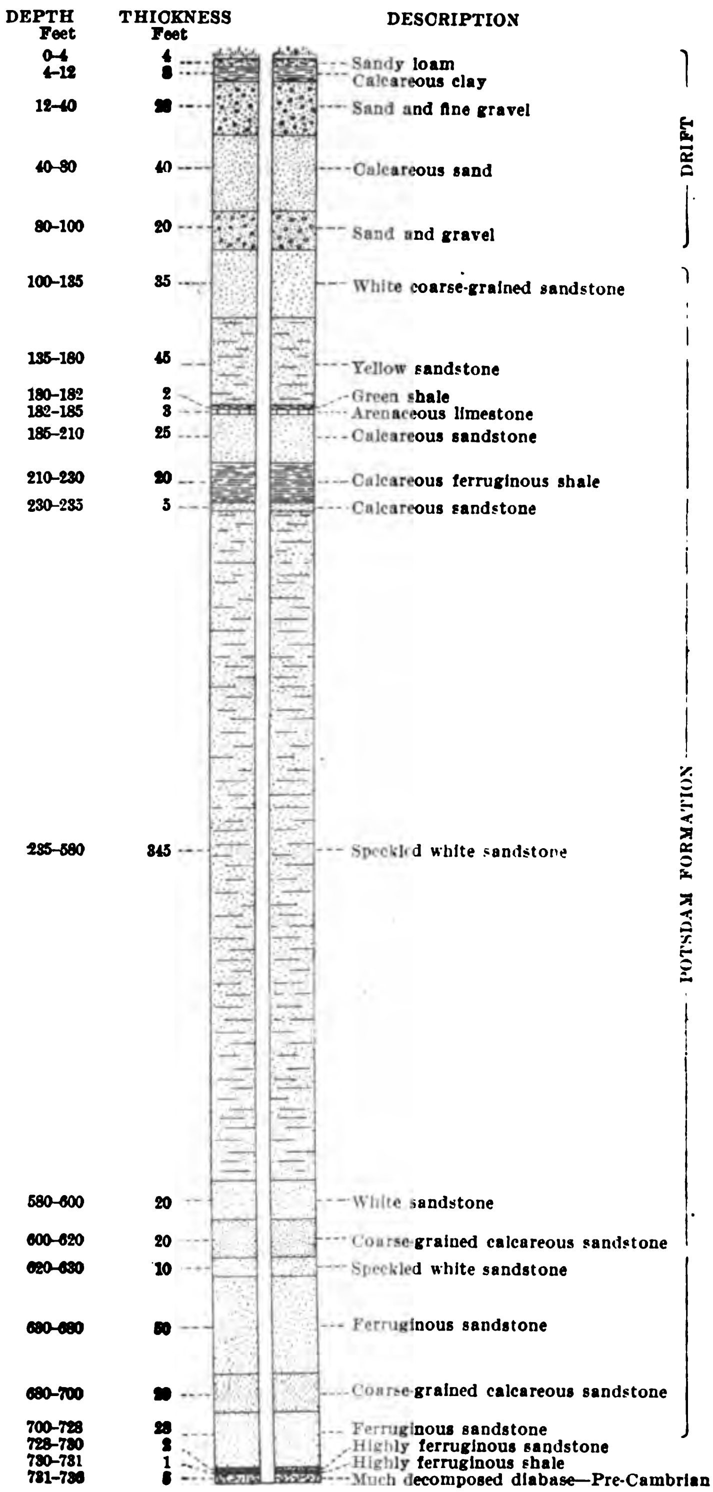

Fig 20.- Geologic Section Illustrating Character of the Strata in the City Wells of Madison.

tion. Experience indicated that it would not be economical to sink more in connection with the present system, as the influence of the present well extends over a considerable distance, which may be seen by the following summary of the tests made.

Tests Showing Interference of Madison Wells.

	Gallons per day.
One well at the pumping station	350,000
Four wells at the pumping station	1,000,000
Four wells at the pumping station and four wells scattered along a line within 3,000 feet	1,750,000
Four wells at pumping station and one remote well	1,300,000

Tests of the artesian well at the C. M. & St. P. roundhouse, a mile distant, failed to show any effect of the pumping at the city wells.

Additional wells could, therefore, be drilled at a distance of about a mile in either direction from the present system of wells at right angles to the direction of the flow without any decrease at the present wells. This plan, however, would necessitate a subsidiary pumping station, and was not resorted to.

To pùmp water from an increased depth there are two praticable methods. First, by sinking a large shaft and placing ordinary suction pumps at the bottom, and then connecting by tunnels to a sufficient number of wells: second, by using so-called deep-well pumps, which are designed to be placed at any desired depth.

Four deep well pumps were recently installed. These pumps have very large capacities and can readily be applied to the present system. The efficiency of the deep-well pumps installed is about 50 per cent, considerably above the theoretical requirements. One of these pumps has been installed at well No. 10, and another at the remote 8-inch well, No. 5, thereby increasing the capacity of the system from 1,750,000 to 4,000,000 gallons per day. In 1911 deep-well pumps were installed at well No. 9, and in the new well, No. 11. This new well, No. 11, is located about half a mile from the waterworks station, and has an estimated daily capacity of 1,000,000 gallons, the well being lowered about 18 feet when pumped at this rate. That the capacity of the Madison system could be further increased and made to furnish double the present supply by installing a first-class shaft and tunnel system can scarcely be doubted. Of the 700,000,000 gallons used in 1911, about one-third was pumped by the direct suction system from the 7 wells located on and near the water-

works station, and about two-thirds, by 4 deep-well pumps at the 4 wells located some distance from the station. In 1914, 90 per cent of the supply was pumped by deep well pumps, and 10 per cent by the new air lift system.

In 1911, and also previous to that time, tests were made as to the sanitary condition of the water supply. In the examination made by the State Hygienic Laboratory in 1911 it was found that the supply from the wells on the direct suction system was never uniformly good, but that the bacterial content of the water from these wells seemed to increase after heavy rains, indicating some connection with contaminated groundwater. It is the general opinion that contaminated surface water is likely to be drawn into the artesian water supply when pumped by the direct suction system.

Stoughton.—This city having a population of 4,761, has a water supply and sewage system. The water supply is obtained from two artesian wells, each 1,011 feet deep. An auxiliary supply from the Yahara river, one intake at a depth of 6 feet, is also available. The daily pumpage is 88,000 gallons. About 800 houses are connected with the supply. Sewage is emptied, without treatment, into the Yahara river.

The section of the city well, No. 2, is as follows:

Section of well No. 2 at Stoughton.

Formation.	Thickness.
	Feet.
Drift	201
Upper Cambrian (Potsdam) sandstone	810
Total	1,011

Sun Prairie.—The population of Sun Prairie is 1,119. The Sun Prairie city supply is from a 10-inch well, 712 feet deep, cased to a depth of 153 feet. Formerly the supply was taken from a well 212 feet deep, improperly cased, the supply being contaminated with marsh water. During a period of three years the level of the marsh water was lowered about 13 feet. The new supply is very satisfactory and has a capacity of 500 gallons per minute. The city uses a Wood's deep well pump, and raises the water 60 feet. Pumping lowers the water about 15 feet. The average daily pumpage is 123,000 gallons. The total number of service connections is 176[1].

[1] For details of water pressures in this well, see W. G. Kirchoffer, Bull. Univ. of Wis. 106, p. 232.

Section of the city well of Sun Prairie.

Formation.	Thickness.
Pleistocene	Feet.
Drift	38
Gravel	8
Lower Magnesian	
Limestone	32
Upper Cambrian (Potsdam)	
Sandstone (lost 19 feet of water)	32
Red grey sandstone	22
Grey limestone	6
Reddish sandstone	67
Red sandstone (lost 7 feet of water)	15
Red sandstone	50
White sandstone	6
Pink shale	38
Reddish sandstone	9
Fine red sandstone	48
Coarse sandstone	7
Total	712

Oregon.—The population is 712. The city water supply is obtained from a 6-inch well, 175 feet deep, in drift and sandstone. The estimated daily capacity of the well is 100,000 gallons; the daily pumpage is about 60,000 gallons. About 50 per cent of the houses connect with the city supply. The private wells vary in depth from 40 to 200 feet.

Mount Horeb.—The population is 1,048. The city water supply is obtained from an 8-inch well, 217 feet deep. The water is obtained from the St. Peter sandstone, the water level standing 90 feet below the surface.

Cambridge.—The population is 507. The city supply is obtained from an 8-inch well, 200 feet deep, from the St. Peter sandstone.

Mazomanie.—The population of this village is 917. The village supply for both fire and domestic use is obtained from 10 driven wells, 25 feet deep, spaced 8 to 10 feet apart, in two parallel rows. The water is obtained from a gravel bed. The average daily pumpage is 4,000 gallons. There are 30 service connections.

Black Earth.—The population of Black Earth is 479. The water supply is obtained from private wells, driven about 20 feet into a bed of sand and gravel.

Middleton.—The population of this vilage is 679. The village supply is obtained from a 10-inch well, 200 feet deep. The estimated capacity is 80,000 gallons; the daily pumpage is 17,000 gallons. About 50 per cent of the houses are reported to connect with the village suply.

Deerfield.—The population is 533. The village supply is obtained from two wells, 6 and 8 inches in diameter, 129 and 152 feet deep, 20

feet in drift and the remainder in rock. About 50 per cent of the houses are reported to connect with the supply. Private wells are from 20 to 80 feet deep.

QUALITY OF THE WATER

The waters of Dane County are either hard or very hard waters, though almost wholly of only moderate mineral content. The surface waters, those of the lakes and rivers, are appreciably lower in mineral content than the groundwater supplies. The water from the Galena-Platteville (Trenton) limestone, and the St. Peter sandstone, appears to contain the highest content of mineral matter. The Madison artesian water supply, obtained from the Upper Cambrian sandstone, contains approximately the same amount of mineral matter as the water of wells in surface deposits. Most of the waters from various sources throughout the county are carbonate waters and are much the same in chemical composition. Only two of the waters analyzed, Nos. 7 and 8, from surface deposits, are sulphate waters.

The lower content of mineral in the Lake Mendota water than in the surrounding groundwater and spring supplies, is very apparently due largely, though not wholly, to the loss of lime, either through the work of organisms or through chemical precipitation in the lakes. In all the groundwater of Wisconsin of carbonate character there is very generally an excess of lime over magnesia in the proportion of 2 to 1. In the lake water, however, through the growth of *chara* and the shells of molluscs, a certain amount of lime carbonate is utilized, and hence, the lake waters and the Yahara River water, as shown in the analyses, contain a smaller amount of lime than of magnesia. In general there appears to be a loss of from 25 to 50 per cent of the calcium, through organic and chemical changes wrought within the body of the lake.

The water from the Yahara River, analyses No. 3, contains 1.48 pounds of incrusting solids in 1,000 gallons; that from the artesian well in Madison, No. 9, contains 2.46 pounds in 1,000 gallons, while that from the well at Mt. Horeb, No. 8, contains 4.13 pounds in 1,000 gallons.

Mineral analyses of water in Dane County.

(Analyses in parts per million.)

	River.		Lake.	Spring.	
	1.	2.	3.	4.	5.
Silica (SiO_2)	0.3	....	15.2	16.6	18.
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	0.3	11.1	2.2	4.3	....
Aluminum oxide (Al_2O_3)	....	....	....	....	7.
Calcium (Ca)	33.0	54.8	19.8	57.3	77.8
Magnesium (Mg)	26.2	29.9	21.6	32.0	42.0
Sodium (Na)	7.5	5.1	3.6	3.4	1.9
Potassium (K)			2.2		
Carbonate radicle (CO_3)	108.0	161.0	77.2	165.8	213.5
Sulphate radicle (SO_4)	11.4	trace	15.3	3.7	7.6
Chlorine (Cl)	9.2	1.8	3.0	5.2	7.0
Organic matter	....	....	....	17.4	....
Total dissolved solids	196.	264.	160.	288.	375.

	Surface deposits.				
	6.	7.	8.	9.	10.
Depth of well ... feet	12	14	25	238	28
Silica (SiO_2)	2.2	14.9	1.5	2.2	undet.
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	....	2.9			
Aluminum oxide (Al_2O_3)	....	....	....	....	
Calcium (Ca)	67.2	29.5	51.9	87.4	94.9
Magnesium (Mg)	33.8	32.6	38.3	41.7	46.5
Sodium (Na)	9.4	5.9	14.4	18.4	9.3
Potassium (K)					
Carbonate radicle (CO_3)	192.4	112.8	172.7	234.4	173.1
Sulphate radicle (SO_4)	4.7	18.8	14.5	55.9	133.8
Chlorine (Cl)	1.5	9.1	11.5	7.4	....
Total dissolved solids	311.	227.	305.	447.	458.

1. Yahara River at Madison. Analyst, G. M. Davidson, for C. & N. W. Ry. Co., Mar. 1894.
2. Black Earth Creek at Mazomanie. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 3, 1891.
3. Lake Mendota—Mean of two Analyses. Analyst, E. B. Hall and C. Juday, Wisconsin Survey Bull. 22, p. 170, Sept. 9, 1907.
4. Bryant's Silver Spring, Madison. Analyst, Paul Fisher.
5. White Cross Spring, Madison. Analyst, Columbus Laboratories, Jan. 7, 1914.
6. Well of C. M. & St. P. Ry. Co., Cross Plains. Analyst. Chemist C. M. & St. P. Ry. Co., Nov. 3, 1891.
7. Well of C. & N. W. Ry. Co., Riley. Analyst, G. M. Davidson, Feb. 2, 1909.
8. Well of C. M. & St. P. Ry. Co., Mazomanie. Analyst, Chemist C. M. & St. P. Ry. Co., June 3, 1893.
9. Well of C. M. & St. P. Ry., Stoughton. Analyst, Chemist C. M. & St. P. Ry. Co., Sept. 20, 1889.
10. Well of C. M. & St. P. Ry. Co., Stoughton. Analyst, G. N. Prentiss, Feb. 6, 1902.

Mineral analyses of water in Dane County—Continued.

(Analyses in parts per million.)

	Galena-Platteville dolomite.		St. Peter Sandstone.	
	11.	12.	13.	14.
Depth of well ... feet..	188	153	60	214
Silica (SiO_2)	5.9	14.9	16.1	17.9
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	1.0	1.2	20.9	2.7
Calcium (Ca)	72.2	72.0	79.8	74.8
Magnesium (Mg)	37.3	40.2	25.7	64.8
Sodium (Na), Potassium (K)	44.0	5.8	37.7	9.7
Carbonate radicle (CO_3)	172.2	178.9	72.6	167.9
Sulphate radicle (SO_4)	16.5	45.1	177.0	166.6
Chlorine (Cl)	77.7	8.9	58.0	15.0
Organic matter	....	....	35.9	....
Total solids	427.	367.	488.	520.

	Upper Cambrian (Potsdam) sandstone.							
	15.	16.	17.	18.	19.	20.	21.	22.
Depth of well ... feet..	736	751	1.015	1.011	85	800	749	332
Silica (SiO_2)	7.0	....	26.	2.7	15.5			
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	1.3	....	6.	10.5	2.8	undet.	undet.	undet.
Aluminium oxide (Al_2O_3)	....	Trace.	....	....	....			
Iron (Fe)	....	1.1	....	....	....	....	....	....
Calcium (Ca)	63.6	64.4	58.5	60.2	61.0	74.3	74.6	57.5
Magnesium (Mg)	34.1	36.5	35.4	41.2	35.9	41.2	38.9	32.6
Sodium (Na)	5.8	8.6	28.	2.2	17.8	5.2	12.6	7.2
Potassium (K)		1.8						
Carbonate radicle (CO_3)	154.1	194.7	198.2	184.4	168.8	191.2	195.0	169.9
Sulphate radicle (SO_4)	25.5	5.6	19.2	12.0	48.2	43.8	35.3	4.1
Chlorine (Cl)	8.2	3.0	7.	3.5	5.3	....	8.2	5.1
Total solids	300.	316.	378.	317.	355.	356.	365.	276.

11. Well of Hanson & Schneider's Mill, Mt. Horeb. Analyst, G. M. Davidson.
12. Well of C. & N. W., Blue Mounds. Analyst, G. M. Davidson, Jan. 22, 1909.
13. Well of C. & N. W. Ry. Co., Klevenville. Analyst, G. M. Davidson, Jan. 30, 1909.
14. Well of C. & N. W. Ry. Co., Stock Yards, Mt. Horeb. Analyst, G. M. Davidson, May 9, 1909.
15. Artesian well, Madison. Analyst, G. M. Davidson, Mar. 1894.
16. Well of City Water Supply, Madison. Analyst, W. W. Daniells.
17. Well of State Capitol, Madison. Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 32, 1877.
18. Well of City Water Supply, Stoughton. Analyst, Dearborn Drug & Chem. Co., Jan. 15, 1903.
19. Well in city quarry, Madison. Analyst, Dearborn Drug & Chem. Co., Mar. 22, 1912.
20. Well of C. M. & St. P. Ry. Co., Madison. Analyst, G. N. Prentiss, Feb. 9, 1902.
21. Well of C. M. & St. P. Ry. Co., Madison. Analyst, G. N. Prentiss, Feb. 11, 1911.
22. Well of C. M. & St. P. Ry. Co., Windsor. Analyst, G. N. Prentiss, Mar. 22, 1907.

Dodge County

Dodge County, located in the southeastern part of the state, has an area of 884 square miles and a population of 47,436. About 90.4 per cent of the county is in farms, of which 75.1 per cent is under cultivation.

SURFACE FEATURES

The surface of Dodge County presents no prominent reliefs, but consists mainly of broad valley bottoms and gently sloping uplands. The entire county is occupied by drift largely deposited by the latest glacial invasion. Undrained marshes and lakes are common. Fox Lake and Beaver Lake are prominent lakes located in the northwestern part of the county. Rock river and its tributaries, Beaver Dam river and Crawfish river, are the principal streams. The valley bottom of the Rock river at Watertown is a little above 800 feet above sea level. The general level of the Horicon marsh, which covers an area of about 50 square miles along the west branch of the Rock, north of Horicon, is about 860 feet. Mud Lake, Beaver Dam Lake and Fox Lake on the Beaver Dam river are respectively 780, 873 and 895 feet above sea level. The land in the eastern part of the county on the divide between the Rock river and the Lake Michigan drainage, is higher than that of the central and western part, the divide usually reaching 1,150 to 1,200 feet above sea level. The uplands are usually less than 200 feet, and rarely exceed 300 feet, above the adjacent valley bottoms.

GEOLOGICAL FORMATIONS

The geological formations range from the Lower Magnesian limestone in the western part of the county, through the St. Peter sandstone, the Galena-Platteville (Trenton) limestone and the Cincinnati shale up to the Niagara limestone on the eastern border. In the southwestern part of the county at Waterloo are a few outcrops of the Pre-Cambrian quartzite. Glacial drift of variable thickness overlies the several bed rock formations, and a variable amount of alluvial sand and gravel associated with the drift fills the valleys. The geological structure is illustrated in Fig. 31.

The thickness of the surface formation is quite variable on account of the uneven surface upon which these deposits were laid down. In the

filled valleys of the pre-glacial rivers a thickness of 250 to 300 feet of sand and gravel may be expected, while on the uplands the usual thickness of the drift is probably less than 100 feet. The thickness of the rock strata is also quite variable on account of the great diversity in the amount of erosion. As indicated in the cross section of the formations, Figure 31, it is only where a formation is protected by the next for-

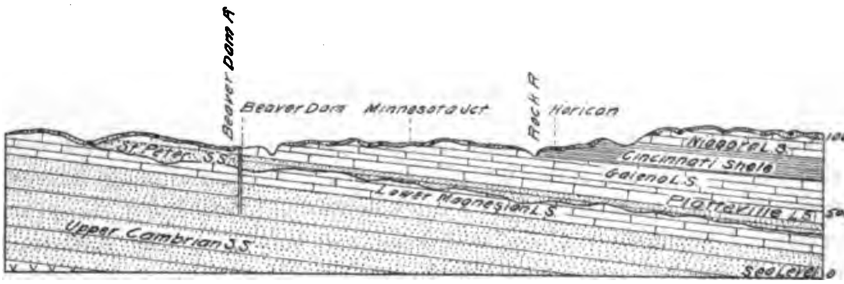

Fig. 31.—Geologic section, east-west, across central Dodge county.

mation above that the entire or maximum thickness is preserved. In the western part of the county the complete thickness of only the Upper Cambrian (Potsdam) sandstone is usually preserved, while in the eastern part, where the Niagara limestone caps the uplands, the complete thickness of all the strata under the Niagara is present.

The approximate range in thickness of the formations in the western half of the county, and also in the eastern half, may be summarized as follows:

Approximate range in thickness of formations in western half of Dodge County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Galena-Platteville (Trenton) limestone	0 to 200
St. Peter and Lower Magnesian formations	0 to 250
Upper Cambrian (Potsdam) sandstone	500 to 800
Pre-Cambrian granite or quartzite	....

Approximate range in thickness of formations in eastern half of Dodge County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone	0 to 200
Cincinnati shale	0 to 220
Galena-Platteville (Trenton) limestone	100 to 250
St. Peter and Lower Magnesian formations	200 to 250
Upper Cambrian (Potsdam) sandstone	600 to 800
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the St. Peter sandstone, the Galena-Platteville (Trenton) limestone and the glacial drift. The other geological formations especially the Upper Cambrian (Potsdam) sandstone also furnish an abundant supply wherever they can be conveniently drawn upon. The county as a whole is relatively flat lying, and usually wells are shallow, varying from 20 to 60 feet in drift or in the underlying rock.

FLOWING WELLS

Flowing wells from the surface deposits occur at Herman, and from the underlying sandstone, the St. Peter, Lower Magnesian and Upper Cambrian horizons along the Rock river and its tributaries. The flows are not as strong as those farther down the Rock river valley in Jefferson County. Flowing wells occur at Reeseville and Beaver Dam, as described on the following pages. (See also pages 75 and 97.

WATER SUPPLIES FOR CITIES AND VILLAGES

Beaver Dam.—The population of Beaver Dam, situated on Beaver Dam Lake, is 6,758. The city has both a ground water and artesian water supply. The ground water well is 20 feet in diameter and 20 feet deep, and supplies 450,000 gallons per day, not sufficient for the ordinary demand, which is about 700,000 gallons per day. The sewage, without treatment, is drained into the Beaver Dam river. About 80 per cent of the people use the water and sewage system.

The artesian water supply is obtained from two 6-inch artesian wells, one 308 and the other 504 feet deep. The elevation of the curb is 885 feet, and the water flows a foot above the surface from the 504 foot well, and rises to the surface in the 308 foot well. The artesian water is said to carry much iron in solution, and to be brown in color.

The two waterworks wells are cased to rock, but P. Spellman's well which is 208 feet deep and flows 2 feet above the surface, is cased only through 20 feet of clay, though it is reported not to have struck rock until 80 feet of clay and gravel were passed through. The flow in Spellman's well was considerably increased after drilling the deep waterworks well, the latter no doubt partly feeding the upper strata of the sandstone.

Section of the Beaver Dam Water Co's. well.

Formations.	Thickness.
	Feet.
Clay and marsh muck	20
Galena Trenton limestone	55
Sandstone. red brown	175
Sandstone, coarse white, much water	15
Sandstone, yellow	110
Sandstone, hard white	129
Total	504

The surface formations in the river valley at Beaver Dam either lies directly upon the Trenton limestone or the St. Peter sandstone, and the latter rests upon sandstone of the Lower Magnesian and Upper Cambrian (Potsdam) horizons. The ridges are capped by Galena-Platteville (Trenton) limestone and most of the wells on higher ground get their supply from this formation.

Mayville.—The population is 2,282. The city has a water supply and sewage system, recently installed. The water supply is obtained from two artesian wells 670 and 855 feet deep, 8 and 9 inches in diameter. The source of supply is mainly from the St. Peter and Potsdam sandstones. The yield is reported to be 144,000 gallons per day. The average daily pumpage is about 50,000 gallons. Total number of water connections is 270. The sewage is pumped to a system of sedimentation, the capacity of the settling basins being 30,000 gallons.

Horicon.—The population is 1881. The city has a municipal water supply but no sewage system. Private sewers empty into the river. The water system was completed in Nov. 1912 and a sewage system will soon be installed. The water supply is obtained from two flowing wells 600 feet deep, 10 in. diameter for 100 feet, and 8 in. diameter the remaining distance. Both wells flow sufficiently for present requirements (Dec. 1912). The pumpage capacity is 600 gallons per minute. A large per cent of the houses have already been connected up with the water system.

The log of the city wells is as follows:

Log of two Horicon city wells.

Formation.	Thickness.
	Feet.
Surface formations	60
Galena-Platteville (Trenton) limestone	190
St. Peter (and Lower Magnesian) sandstone	250
Upper Cambrian (Potsdam) sandstone	200
Total	600

Reeseville.—The population is 352. The water is obtained from the Trenton limestone, or from its contact with St. Peter sandstone. Flows are struck on low ground. Wells range in depth from 20 to 200 feet.

Section of Well owned by P. Runkle, Reeseville.

Formation.	Thickness.
	Feet.
Clay	20
Hardpan	62
Gravel	15
"Shell Rock"	13
Limestone	30
Total	140

Juneau.—The population of Juneau is 1,003. The city water supply is obtained from a 6-inch well 350 feet deep, cased 30 feet. The water in the well stands 70 feet below the ground, and the average daily pumpage is about 20,000 gallons. About 75 per cent of the families use the city water. No sewage system is installed.

At Burnett Junction the Chicago & Northwestern Railroad well is about 50 feet deep and flows one foot above the surface. At Lowell, the well of G. Ganes is 380 feet deep, obtaining water from the St. Peter sandstone horizon. At Clyman the deepest wells are 144 and 150 feet deep in the Trenton limestone.

Randolph.—The population of Randolph is 937. The village has a public supply, mainly for fire purposes, obtained from an 8-inch well 300 ft. deep, daily capacity 140,000 gallons. Only a small percentage of houses connect with the system. Private wells are generally from 30 to 60 feet deep.

The drillers log of the 240 foot well at South Randolph, a station on the C. & N. W. Ry. is as follows:

Driller's log of C. & N. W. Ry. Co. well at South Randolph.

Formation.	Thickness.
	Feet.
1. Glacial drift	38
2. Limestone	108
3. Brown sandstone	2
4. Blue sandstone	2
5. Green sandstone	5
6. Red sandstone	70
7. Green sandstone	6
8. White sandstone	9
Total	240

Analyses of this water is No. 29 in the table. No. 2 in the above log is probably the Lower Magnesian limestone, and Nos. 3 to 8 Upper Cambrian (Potsdam) sandstone. This well supplied, on a pumping test, 62,000 gallons in 10 hours.

Clyman Jct.—The well of the C. & N. W. Ry. Co. at Clyman Jct., depth 335 feet has the following section:

Drillers log of C. & N. W, well at Clyman Junetion.

Formation.	Thickness.
	Feet.
1. Loose earth	30
2. Limestone	238
3. Sandstone	67
Total	335

No. 1 is glacial formation, No. 2 is Galena-Platteville (Trenton) limestone, and No. 3, St. Peter sandstone. The water analysis of this well is No. 28 in the table of analyses.

Ashippun.—At Ashippun station two wells were drilled in 1912 by the C. & N. W. Ry. Sections of these wells, 345 and 458.3 feet deep, have the following driller's logs:

Driller's logs of two C. & N. W. Ry. wells at Ashippun.

Formation.	Thickness.	
	Feet.	Feet.
1. Black soil	5	5
2. Quicksand	12	18
3. Shale	66	66
4. Shale and blue clay	22	22
5. Lime rock	82	39
6. Sandstone	3	76.3
7. Green shale	....	2
8. Hard crystallized limestone	205	215
9. Green shale and calcite crystals	....	15
Total	345	458.3

These wells are 160 feet apart. The 458.3 foot well differs from the 345 foot well in having a very thick sandstone bed represented by No. 6. Nos. 1 and 2 are glacial and alluvial formations. Nos. 3 to 7 are probably within the Cincinnati shale group, the transition beds being represented by 6 and 7. Nos. 8 and 9 are probably within the Galena-Platteville (Trenton) group. The analyses of water from these wells are shown in the table of analyses, Nos. 20 and 21. Both are hard carbonate waters and contain a small amount of hydrogen sulphide gas. Water in the 345 foot well rises within 13 inches of top of well.

QUALITY OF THE WATER

The mineral content of the waters of Dodge County is shown in the several tables of analyses. About one-half the waters analyzed are hard waters, and one-half are very hard waters. The waters from the railroad wells at Juneau and Rubicon are unusually hard water from the surface formations, which may be due to the occurrence of material from the Cincinnati shale formation in the surface deposits at these places. Most of the waters are carbonate waters. Analyses No. 13, 16, 26 and 27 are of sulphate waters. The creek waters, Nos. 3 and 4, are relatively high in mineral matter for surface waters in Wisconsin. The water from the creek at Burnett Jct., No. 4, contains 2.77 pounds of incrusting solids in 1,000 gallons; the water from the C. & N. W. Ry. well at South Randolph, No. 29, contains 2.64 pounds in 1,000 gallons; and that from the railroad well at Juneau, No. 8, contains 4.74 pounds in 1,000 gallons.

Mineral analyses of water in Dodge County.

(Analyses in parts per million.)

	River.		Creek.		Springs.		
	1	2	3	4	5	6	7
Silica (SiO_2)	....	....	14.0	14.9	22.0	....	12.2
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	....	2.0	1.5	....	....	
Aluminium oxide (Al_2O_3)	....	....	....	....	4.5	2.9	....
Iron (Fe)	....	....	....	....	.5	....	....
Calcium (Ca)	49.7	49.5	72.6	71.7	76.1	66.1	65.3
Magnesium (Mg)	46.1	37.4	37.4	37.7	43.9	33.8	36.7
Sodium and potassium (Na+K)	3.7	6.6	4.1	10.3	7.3	1.6	6.6
Carbonate radicle (CO_3)	175.7	151.4	177.4	186.6	216.	179.5	167.0
Sulphate radicle (SO_4)	15.7	26.3	34.3	20 1	7.8	5 4	30.8
Chlorine (Cl)	8.3	8.2	6.3	15.8	11.2	2.4	9.9
Total dissolved solids	299.	279.	348.	359.	389.	292.	329.

	Surface deposits.						
	8	9	10	11	12	13	14
Depth of well.........feet	14	20	40	40	16	24	24
Silica (SiO_2)	15.5	....	....	....	4 0	undet.	1.7
Aluminium and iron oxides (Al_2O_3)+Fe_2O_3)	1.0	....	....	....			
Aluminium oxide (Al_2O_3)	....	....	....	....			
Iron (Fe)	....	.9	....	....	....	....	....
Calcium (Ca)	120 3	58.9	90.8	109.2	37.0	113.0	86.6
Magnesium (Mg)	62.0	32.0	53.0	55.0	29.0	61.2	43.5
Sodium and potassium (Na+K)	40.5	10.4	15.5	6.8	4.2	9.6	6.4
Carbonate radicle (CO_3)	278 1	166.7	204.7	210.5	127.3	180.1	186.5
Sulphate radicle (SO_4)	102.8	17.0	119.7	144 7	2.6	222.6	79.8
Chlorine (Cl)	53.7	4.4	9.6	10.4	4.4	14.7	10.0
Total dissolved solids	674.	290.	493.	537.	209.	601.	414.

1. Rock River at Horicon Junction. Analyst, G. N. Prentiss, April 3, 1908.
2. Rock River at Mayville. Analyst, G. N. Prentiss, Oct. 5, 1910.
3. Honey Creek near Lowell. Analyst, G. M. Davidson, Sept. 22, 1910.
4. Creek at Burnett Junction. Analyst, G. M. Davidson, June 23, 1896.
5. Peerless Spring, Fox Lake. Analyst, G. Bode.
6. Woodland Spring, Woodland. Analyst, Chemist C. M. & St. P. Ry. Co., July 9, 1889.
7. Spring of Paul O. Hustings, Mayville. Analyst, Chemist, C. M. & St. P. Ry. Co.
8. Well of C. & N. W. Ry. Co., Juneau. Analyst, G. M. Davidson, June 23, 1896.
9. Railroad well at Fox Lake Junction. Analyst, Chemist C. M. & St. P. Ry. Co., Sept. 30, 1889.
10. Private well at Horicon. Analyst. Chemist C. M. & St. P. Ry. Co., May 9, 1901.
11. Railroad well at Rubicon. Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 19, 1902.
12. Railroad well at Mayville. Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 10, 1889.
13. City well at Mayville. Analyst, G. N. Prentiss, Sept. 14, 1905.
14. Railroad well at Horicon Junction. Analyst, Chemist C. M. & St. P. Ry. Co., July 8, 1889.

***Mineral analyses of water in Dodge County*—Continued.**

(Analyses in parts per million.)

	Surface deposits.				Galena-Platteville limestone.		
	15	16	17	18	19	20	21
Depth of well	25	40	42	40	120	345	458.3
Silica (SiO_2)	undet.	undet.		17.1	22.2	11.8	12.5
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)			undet.	1.5	.5	1.0	4.9
Calcium (Ca)	109.9	101.5	115.1	62 6	64.5	68.0	69.5
Magnesium (Mg)	57.8	46.3	60.7	44.9	39.3	37.9	30.1
Sodium and potassium (Na+K)	6.8	17.6	18.2	5.3	10.8	20.9	8.1
Carbonate radicle (CO_3)	211.0	165.3	211.2	201.9	190.6	211.5	180.1
Sulphate radicle (SO_4)	145.0	197.9	34.9	12.6	5.2	6.0	7.4
Chlorine (Cl)	17.3	....	50.2	2.0	14.0	8.7	5.6
Nitrate radicle (NO_3)	....	....	144.7	....	....	....	....
Total dissolved solids	548.	529.	635.	348.	347.	366.	318.

	Lower Magnesian limestone.	St. Peter and Upper Cambrian (Potsdam) sandstone.						
	22	33	24	25	26	27	28	29
Depth of well.......feet	154	284	130	....	232	426	335	240
Silica (SiO_2)	9.9	13.1	12.0	1.4	un-	....	14	19.5
Aluminium and iron oxides							.9	
($Al_2O_3+Fe_2O_3$)	1.5	.5	2.0	2.3	det.	8.6	1.0	0.7
Iron (Fe)	....	....	2.2	....	....	....	....	....
Calcium (Ca)	65.3	67.1	98.0	61.1	82.6	110.7	68.2	62.4
Magnesium (Mg)	31.4	35.5	61.0	32.0	39.6	40.6	36.2	39.2
Sodium and potassium (Na+K)	4 3	1.8	1.0	11.6	13.3	99.0	2.2	2.9
Carbonate radicle (CO_3)	165.1	181.8	287.0	170.4	132.3	173.6	185.4	170.8
Bicarbonate radicle (HCO_3)	....	....	2.36	....	....	....	....	....
Sulphate radicle (SO_4)	19.2	12.7	18.0	14.7	141.0	328.1	12.3	31.2
Chlorine (Cl)	4.6	1.7	1.5	7.0	18.8	18.9	2.0	4.6
Organic matter	....	....	21 0	....	....	....	....	....
Nitrate radicle (NO_3)	....	....	....	....	4.3	....	....	....
Total dissolved solids	301	314.	485.	301.	432.	780.	322.	331.

15. Well of Rubicon Malt & Grain Co., Rubicon. Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 19, 1902.
16. Well C. M. & St. P. Ry. Co., Horicon Junction. Analyst, G. N. Prentiss, April 11, 1902.
17. Well of Joseph Hauser, Rubicon. Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 19, 1902.
18. Well of A. Swenson, near Ashippun. Analyst, G. M. Davidson, Nov. 14, 1910.
19. Well of J. Drew near Ashippun. Analyst, G. M. Davidson, Nov. 14, 1910.
20. Well of C. & N. W. Ry. Co., Ashippun. Analyst, G. M. Davidson, May 6, 1912.
21. Well of C. & N. W. Ry. Co., Ashippun. Analyst, G. M. Davidson, May 29, 1912.
22. Well of J. Kuhlman, Lowell. Analyst, G. M. Davidson, Nov. 22, 1910.
23. Well of C. & N. W. Ry. Co., South Randolph. Analyst, G. M. Davidson, Jan. 13, 1911.
24. Well of Woolen Mill at Beaver Dam.
25. City Water Supply, from Wells, Beaver Dam. Analyst, Dearborn Drug & Chem. Co., Jan. 21, 1910.
26. Well of C. M. & St. P. Ry. Co., Horicon Junction. Analyst, G. N. Prentiss, Mar. 18, 1912.
27. City well Mayville. Analyst, G. N. Prentiss, Sept. 14, 1905.
28. Well of C. & N. W. Ry. Co., Clyman Junction. Analyst, G. M. Davidson, Sept. 25, 1911.
29. Well of C. & N. W. Ry. Co., South Randolph. Analyst, G. M. Davidson, July 6, 1911.

Door County

Door County, forming the main body of the peninsula between Green Bay and Lake Michigan, has an area of 454 square miles and a population of 18,711. About 84.2 per cent of the county is in farms of which 53.4 per cent is under cultivation.

SURFACE FEATURES

Door County, with the exception of its southern boundary adjacent to Kewaunee county, is bounded on all sides by the waters of Green Bay and Lake Michigan. It is a broad upland ridge reaching up to 200 and 300 feet above lake level, and having a relatively gentle slope to the southeast, and a steep slope, often with precipitous cliffs, on the west adjacent to Green Bay.

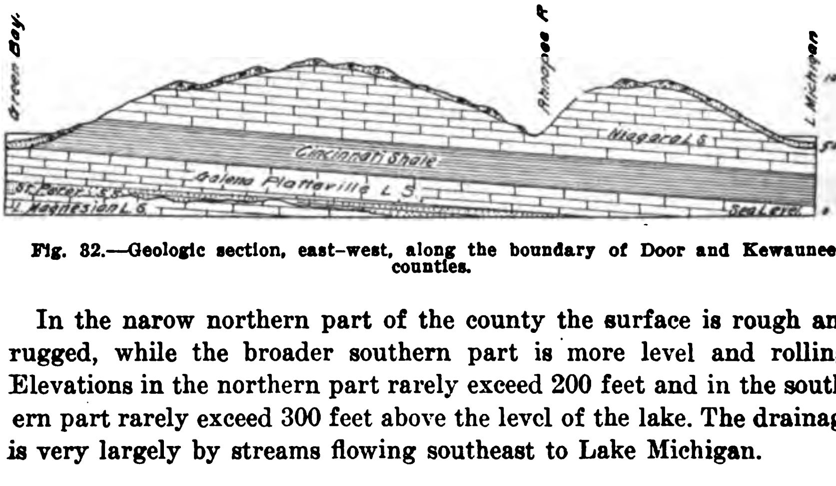

Fig. 32.—Geologic section, east-west, along the boundary of Door and Kewaunee counties.

In the narow northern part of the county the surface is rough and rugged, while the broader southern part is more level and rolling. Elevations in the northern part rarely exceed 200 feet and in the southern part rarely exceed 300 feet above the level of the lake. The drainage is very largely by streams flowing southeast to Lake Michigan.

GEOLOGICAL FORMATIONS

With the exception of a narrow belt of Cincinnati shale in the southwestern part of the county, adjacent to Green Bay, the rock formation at the surface is wholly the Niagara limestone. Outcrops of the limestone are very common in the northern part, but south of Sturgeon Bay over the more level portion the drift covering is more abundant. Besides the surface deposits of glacial drift, there are thick deposits of beach gravels and lacustrine clays adjacent to Lake Michigan. The geological structure is illustrated in figure 32, a cross section east and west along the boundary of Door and Kewaunee counties.

The thickness of the surface deposits is variable but apparently not as great anywhere in the county as in the counties farther south. Over much of the peninsula, no surface deposits overlie the rock, and the maximum thickness of drift is probably not more than 150 or 200 feet.

The thickness of the Niagara limestone, however, is probably as great as in the counties further south. No records of wells are available which have penetrated through this formation in the eastern part of the county where the greatest thickness is likely to be attained. On the upland areas, however, many wells have been drilled to a depth of 200 feet into this formation. At Algoma, (see p. 403), a short distance south of Door County, a thickness of 485 feet of Niagara was penetrated in the new city well. The maximum thickness in Door County is very probably between 450 and 550 feet.

The Cincinnati shale outcrops only in the southwestern part of the county adjacent to Green Bay. The exposed thickness under the Niagara, ranges from about 15 feet at its most northern point of outcrop, south of Little Sturgeon Bay, to 50 or 60 feet at the southern border of the county. In this locality the formation is a hard compact fine grained calcareous shale showing abundant mud cracks.

East of Green Bay on Door Peninsula, three-fourths of a mile from the shore and 18 miles southwest of Sturgeon Bay, a well was drilled by the Calumet Land and Oil Company of Calumet, Michigan, of which the following record was obtained:

Record of well of Calumet Land & Oil Co. Sec. 24, T. 27 N. R. 23 E.

Formation.	Thickness.
	Feet.
Glacial	
Sand and gravel	6
Cincinnati	
Soft greenish blue shale	540
Galena-Platteville (Trenton)	
Limestone and soapstone	120
Sandy limestone (water bearing)	90
Slatey limestone	30
St. Peter	
Sandstone (water bearing)	175
Total depth	961

The thickness of the Cincinnati shale formation in Door County, and for some distance farther south in Kewaunee and Brown counties, as illustrated in the deep well of Joe Vandermessen, near Dyckeville, is of special interest, as stated on page 405.

Another well was drilled near by when prospecting for coal, the material penetrated as reported by Mr. Burns being as follows:

Section of well in Sec. 24, T. 27 N. R. 23 E.

Formation.	Thickness.
	Feet.
Pleistocene	
Soil	5
Cincinnati	
Shale	516
Galena-Platteville (Trenton)	
Limestone	200
St. Peter	
Sandstone	80
Remainder	
(Beds of limestone, sandstone, soapstone, slaty shale, clay, ending in a clay bed)	239
Total depth	1,040

The approximate thickness of the geological formation from the surface down to the Pre-Cambrian in Door County may be summarized as follows:

Approximate thickness of formations in Door County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 200
Niagara limestone	0 to 550
Cincinnati shale	500 to 550
Galena-Platteville (Trenton) limestone	200 to 250
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	300 to 500
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING FORMATIONS

The principal sources of the water supply are the surface deposits and the Niagara limestone. Water can generally be obtained from the gravel seams in the drift and lacustrine deposits where the surface formation attains a thickness of 30 or 40 feet or more.

The Niagara limestone furnishes a good supply of water at depths of a few feet up to 200 feet. On the limestone ridges most of the wells are from 100 to 200 feet in rock.

The Cincinnati shale is impermeable to water and hence no appreciable supply is obtained from this formation. In the small area of outcrop of this formation abundant water is found in the surface gravels overlying the shale.

WELLS IN THE RURAL DISTRICTS

The depth of the wells in Door county is quite variable. In the town of Forestville the wells are 60 to 80 feet in rock; in Jacksonport 50 to 200 feet in rock; in Sawyer 20 to 80 feet in rock; in Sister Bay 50 to 200 feet in rock; and in Vignes 10 to 200 feet in drift and rock.

WATER SUPPLIES FOR CITIES AND VILLAGES

Sturgeon Bay.—The city of Sturgeon Bay, located on Sturgeon Bay, an inlet of Green Bay, has a population of 4,262. The city has a system of waterworks, recently installed, the water supply being obtained from the bay, through one intake, laid at a depth of 8 feet, and from five wells, each 250 feet deep. No records of the wells are at hand, but they probably reached to the approximate base of the Niagara limestone formation. The average daily pumpage is 150,000 gallons, there being about 80 service connections. There are a number of shallow flowing wells in the city, ranging from 25 to 30 feet deep in the gravel and the Niagara limestone. These wells are located on ground 5 to 10 feet above the level of the bay and flow as high as 10 feet above ground.

QUALITY OF THE WATER

No analyses of the water supplies of Door County are at hand. The water of Lake Michigan containing about 140 parts per million of mineral matter, is shown in the table, page 221. The water of Green Bay is likely to be only slightly higher in mineral matter than that of Lake Michigan. The groundwater derived from the surface formation and Niagara limestone are likely to be hard waters ,while that derived from the formations underlying the Cincinnati shale may be very hard water, high in mineral, like that from the Stephenson well at Marinette, or it may be hard water of only moderate mineral content, like that from the new city well at Algoma.

Douglas County

Douglas County, located in the northwestern corner of the state, on Lake Superior, has an area of 1,319 square miles, and a population in 1910 of 47,422. Only about 10.8 per cent of this county is laid out into farms, of which 21.5 per cent is under cultivation. The principal portion of the population is in Superior, a rapidly growing city of 40,284.

SURFACE FEATURES

The principal topographic feature is the ridge extending east and west across the middle part of the county, separating the drainage flowing to Lake Superior on the north from that flowing to the Mississippi River on the south. The elevations vary from 602 feet above sea level on the shore of Lake Superior to 1,200 to 1,500 feet on the divide, about 20 miles to the south. The surface is very gently sloping in the vicinity of Superior, but farther south, and to the east, the land rises more abruptly to the summit of the divide. The slope north of the divide, towards the lake, is relatively steep, while that south of the divide, to the south, is relatively gentle.

GEOLOGICAL FORMATIONS

The geological formations are the Keweenawan trap, the Lake Superior red sandstone, and the surface deposits of lacustrine and glacial clays and gravel. The most common formation is the Keweenawan trap. The Lake Superior red sandstone forms a belt of variable width near the lake.

The surface deposits on the slope towards Lake Superior, especially fringing the lake, consist of alternating beds of clay, sand and gravel, which dip toward the lake. In the southern part of the county irregular deposits of glacial boulders, sand, and gravel predominate at the surface.

The accompanying section (figure 33) illustrates the geological formations along a north-south line through Douglas County.

The thickness of the geological formations is quite variable throughout the county. The granite and Keweenawan trap, which underlie the Lake Superior sandstone and the surface deposits, as elsewhere are of great depth, as they are erupted from deep seated

sources. The thickness of the sandstone at Superior is probably between 5,000 and 10,000 feet, thinning out rapidly towards the trap range.

The glacial deposits over the trap range, and in the southern part of the county, probably vary in depth from 0 to 200 feet. Along the shore of the lake, over the Lake Superior sandstone, the surface de-

Fig. 33.—Geologic section, north-south, across Douglas county.

posits of stratified clays and gravels in places attain a very great thickness. The maximum thicknes of the surface deposits is attained in the old buried valley under the St. Louis river where it is known to have a thickness of nearly 600 feet. The county may be summarized as follows:

Probable range in thickness of formations in Douglas County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 600
Lake Superior sandstone	0 to 10,000
Keweenawan trap	

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the surface formations of glacial drift, and the stratified sands and gravels. Small amounts of water may be obtained from the fractured portions of the trap rocks. The Lake Superior red sandstone contains a variable amount of water, which at Superior appears to be highly mineralized and of salty character, and hence, is generally unfit for use, either for industrial or drinking purposes.

FLOWING WELLS

Flowing wells occur along the shore of the lake, and for some distance to the south on the Superior slope. The source of these flows ap-

pears to be wholly within the surface deposits. The alternating beds of sand, clay and gravel fringe the shore of Lake Superior and dip toward the lake, developing a typical artesian slope. The gathering ground for the water lies south of the lake, on the north slope of the dividing trap ridge, some 15 to 20 miles south of the lake.

At Superior and south of the lake shore, where the artesian slope is developed, much of the water supply is drawn from relatively shallow wells in the superficial deposits of gravel and sand, or from the immediately underlying sandstone and the Keweenawan trap formations. At Itasca, flowing water is obtained at 30 feet, and at Plum Grove, at 40 feet. South of Superior there are flowing wells in sections 22, 27 and 28 of T. 47, R. 14. The wells of H. D. Coyne, John Anderson and Olaf Olson, are in sand and gravel after passing through clay and hard pan, and are 40 to 53 feet deep. There are also some strong chalybeate springs in this locality. An artesian well is also located at Frank Desmond's, 60 feet in gravel, in section 24, T. 47, R. 13.

WATER SUPPLIES OF SUPERIOR

Private wells in and about the city vary in depth from 100 to 500 feet, most of them getting their supply from the gravel beds. Most of the wells along the docks on Lake Superior, and on St. Louis Bay, are, or have been flowing wells, the water rising from 10 to 20 feet above the level of the lake. Similar wells are scattered over various parts of the city, but most of them are not flowing, since the ground lies too high, being for the most part 30 to 60 feet above lake level.

The irregular thickness and variable depth of the water-bearing gravel in Superior is shown by the following experiences. On the same property two wells were put down, the first one to a depth of 181 feet without striking either water or gravel, and after getting salty, red water at 700 feet in the red sandstone the well was abandoned. A new well, started 275 feet from the former, struck the gravel bed carrying an abundant supply of pure, cold water at a depth of 196 feet. On the next block a similar well of abundant good water was obtained after penetrating 110 feet of clay and 45 feet of sandy gravel.

In general there is porous sandstone underlying the drift in the eastern part of the city, and impervious shale beds under the drift in the western part; hence, if water is not struck in the overlying drift in the western part, conditions are unfavorable for getting a supply from the shale beneath.

The log of the Great Northern Elevator Company' well, on St. Louis Bay, is as follows:

Log of Great Northern Elevator Co. well.

Formation.	Thickness.
	Feet.
Clay	85
Drift, sand and gravel	325
Sand with hard pan streaks	111
Gravel and water-bearing sand	4
Total depth	525

At the Hotel Supreior, about a mile from the lake shore, Mr. J. A. Colwell drilled five wells without getting a good supply of water; in most of these wells the drift or gravel material was over 225 feet in depth, but was nearly dry. No doubt this material was of the same nature as the drift above the gravel seam furnishing the water at the Great Northern Elevator Company's well. One of the wells at the hotel was put down to a depth of 420 feet. Here the sandstone, or rather, shale of the Superior sandstone formation, was encountered, at 245 feet. Into this shale the well was drilled 175 feet, obtaining but little water, which gave a saline taste.

The city water supply of Superior has had a varied history. (For details see W. G. Kirchoffer, Bulletin 106, Univ. of Wisconsin, p. 188-9.) The city supply is obtained from 107 wells, from 40 to 45 feet deep, spaced 12 to 15 feet apart, with 4, 6 and 8 inch diameters, with the lower 20 feet of Cook points in sand and gravel. The wells are located on Minnesota Point, a sand spit extending across the mouth of Superior Bay. These wells furnish an abundant quantity of water, and would have been a very simple solution of the water supply problem of Superior had it not been for the fact that the water contains iron in solution, which, on standing, deposited iron oxide, besides supporting a growth of *Crenothrix* in the suction and city mains. To remedy this the company has constructed a sand filter with suitable aerator to remove the iron. The capacity of the aerating and filtering plant is five million gallons per day, and the daily consumption varies from 1,500,000 to 2,500,000 gallons. The sewage is discharged without purification into Superior Bay. About 30 or 40 per cent of the houses have water and sewer connections.

Gordon and Solon Springs.—At Gordon there are dug and driven wells 10 to 80 feet deep, in gravel and sand. At Solon Springs, the wells are generally from 20 to 40 feet deep in the drift. At this place

is a well known mineral spring, from which a large amount of spring water was sold a few years ago.

QUALITY OF THE WATER

No analyses of water from the wells of Douglas County are available. In the table the analyses of the city water supply of Superior from Lake Superior and the water of Lake Superior at Sault Ste. Marie, Michigan, is quoted. The water of Lake Superior is soft water and essentially uniform in low content of mineralization throughout. However, wherever the sewage of cities and refuse from mills, is emptied into the lake it becomes polluted and unsafe for drinking purposes.

The water supply obtained from wells in the surface deposits and crystalline rocks is undoubtedly of good quality and is very likely relatively soft water throughout. On the other hand, the water obtained from the Lake Superior red sandstone, is very likely to be highly mineralized, of salty character, and therefore unfit for industrial and drinking purposes. No mineral analyses of salty water from the sandstone in Superior are available but waters with strong saline taste have been reported from various wells in the city. The occurrence of saline water in the sandstone, however, may be of only local distribution and not of general occurrence throughout this formation. In some of the shallow wells in Ashland fresh water of excellent quality is obtained from the sandstone. (See Analyses 6, 7, and 8, page 333).

Mineral analyses of water in Douglas County.

(Analyses in parts per million.)

	Lake Superior.		Creek.
	1.	2.	3.
Silica (SiO_2)	5.9	7.4	19.5
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)	2.2	....	5.9
Iron (Fe)	....	.06	....
Calcium (Ca)	12.4	13.	9.3
Magnesium (Mg)	3.6	3.1	7.9
Sodium and potassium (Na + K)	7.4	3.2	1.0
Carbonate radicle (CO_3)	31.4	....	33.5
Bicarbonate radicle (HCO_3)	....	56.	....
Sulphate radicle (SO_4)	....	2.1	....
Chlorine (Cl)	6.9	1.1	1.5
Nitrate radicle (CO_3)	....	.5	....
Suspended matter	Trace	Trace	....
Organic matter	....	....	33.5
Total dissolved solids	70.	60.	78.

1. City Water Supply of West Superior—Lake Superior. Analyst, Dearborn Drug & Chemical Co., May 8, 1899.
2. Water from Lake Superior at Sault Ste. Marie, Mich., mean of 11 analyses, U. S. Geol. Sur. W. S. P. No. 236, p. 101, 1906–7.
3. Water from Bluff Creek at Itasca. Analyst, G. M. Davidson, C. & N. W. Ry. Co., July 25, 1901.

Dunn County

Dunn County, located in the northwestern part of the state, has an area of 844 square miles and a population of 25,260. About 83.5 per cent of this county is laid out in farms, of which 52.8 per cent is under cultivation.

SURFACE FEATURES

The surface of Dunn County is generally hilly and uneven, its principal rock outcrop, the Upper Cambrian (Potsdam) sandstone, being deeply trenched by rivers and valleys. In the northern part, the valleys are relatively narrow, while in the southern part, especially along the Chippewa river, the valley plain is broad. Rusk Prairie, the for-

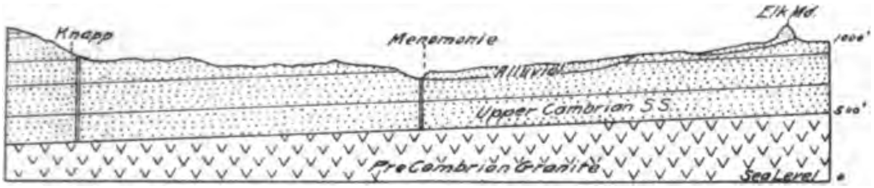

Fig. 34.—Geologic section, east-west; across central Dunn county.

mer course of the Red Cedar, is a broad valley bottom plain, lying east of the narrow valley, now occupied by the Red Cedar. The southwestern part of the county is the eastern portion of the limestone upland extending west across Pierce and St. Croix counties. The altitudes generally range between 800 and 1,000 feet in the valley bottoms to 1,100 and 1,200 feet over the inter-valley areas.

GEOLOGICAL FORMATIONS

The geological formations in the county are the Upper Cambrian (Potsdam) sandstone and the Lower Magnesian limestone. The latter occurs only in the southwestern part. Glacial drift occurs in most parts of the county, but is present in only very small quantity, with the exception of a few places on the limestone uplands. Alluvial sand and gravel forms a thick formation along the Chippewa and Red Cedar rivers, and their tributaries. The geological structure is illustrated in the cross section, Fig. 34.

The surface formation, consisting mainly of the alluvial deposits, has a probable maximum thickness of 200 or 250 feet in the deepest parts of the valleys. The thickness of the hard rock formations is quite variable on account of the extensive erosion of the strata. The complete section of the sandstone is preserved only where protected by the overlying Lower Magnesian limestone on the highest upland ridges. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Dunn County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Lower Magnesian limestone	0 to 150
Upper Cambrian (Potsdam) sandstone	300 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing strata are the sandstone and the alluvial formations. On the valley bottoms wells generally go down 10 to 20 feet for water. On the limestone uplands, especially in the southwestern part of the county, the wells are often 100 to 200 feet deep.

FLOWING WELLS

Flowing wells, so far as known, have been developed only at Menomonie in drilling for the city water supply. Conditions, however appear to be favorable for obtaining artesian flows on low ground along the narrow valley of the Red Cedar river, between Menomonie and Dunnville. It is barely possible also that flowing wells may be obtained up some of the tributary valleys of the Red Cedar, on the west side of the river. The artesian head in Dunn county is not likely to be more than 10 or 15 feet above the valley bottoms.

SPRINGS

Springs are quite common in the western part of the county at the base of the Lower Magnesian limestone, and at the horizon of shale strata within the sandstone formation. The springs are located on the lower slopes and in the bottoms of the valleys, and are often the starting point of the permanent streams. Many of the farm houses are located near springs, which furnish an excellent supply of water for domestic use.

WATER SUPPLIES FOR CITIES AND VILLAGES

Menomonie.—This city, the county seat of Dunn, situated on the Red Cedar river, has a population of 5,036. It is located upon an alluvial terrace of sand and gravel overlying the Potsdam sandstone, the latter formation being exposed quite generally along the Red Cedar river. The city water supply is obtained from two 12-inch wells, 330 and 360 feet deep, (also reported 380 and 412 feet deep), reaching the granite. The elevation of the surface at the wells is 810 feet and the water, when the wells were first drilled, rose 10 feet above the surface. The wells are 500 feet apart, and directly connected with the pumps and to each other. An intake connects with the river, and is used only in case of emergency. The average daily pumpage is estimated at 268,000 gallons. There are 537 service connections. The water contains sufficient hydrogen sulphide to produce a strong odor on coming in contact with the air and leaves a yellowish brown stain wherever evaporation takes place. The sewage, without purification, empties into the river.

Knapp.—At Knapp a deep well was drilled for oil several years ago. The depth of this well is reported to be 635 feet, striking granite at 630. Only about 20 feet of surface sand and gravel was passed through before striking the shale and sandstone. The elevation of the surface at the well is about 970, about 40 feet above the railroad station. The water rises in the well to 40 feet below the surface. The wells in Knapp are generally from 20 to 50 feet deep, depending upon the elevation above the creek.

Meridean.—At Meridean on the Chippewa river is a deep well reaching the granite. The log of this well is as follows:

Log of well at Meridean.

Strata.	Thickness.
	Feet.
Sand	140
Gravel	25
Sandstone	187
Decomposed granite	60
Total	412

The surface of the well is at the same elevation approximately as the railroad station, 746 feet. Granite was struck at 362 feet, or 42 feet higher than the granite at Durand. The shale beds penetrated by wells in Durand have obviously been eroded away at the Meridean

well, their horizon being occupied in the valley by alluvial sand and gravel.

Colfax.—Colfax, having a population of 701, is located on the Red Cedar river. The formation is alluvial sand and gravel, essentially a level plain. The city has under consideration the installation of a water supply and sewerage system. A good supply of water could undoubtedly be obtained by a proper system of wells sunk to a depth of 100 to 150 feet in the alluvial sand and gravel. The private wells in the city are usually from 20 to 40 feet deep.

QUALITY OF THE WATER

The chemical composition of the water supplies from various places in Dunn County is shown in the table of mineral analyses. The water is usually soft in the alluvial deposits within the general area of the sandstone outcrop. The water in the sandstone is hard within the area of the limestone at Weston and also in the deep city wells in Menomonie. The spring water at Meridean, where source of supply is in the sandstone, is very soft water.

The water of the Red Cedar river at Menomonie, Analysis No. 1, contains 0.89 pounds of incrusting solids in 1,000 gallons, while that of the railroad well at Weston, Analysis No. 7, contains 2.14 pounds in 1,000 gallons.

Mineral analyses of water in Dunn County.

(Analyses in parts per million.)

	River.	Springs.		Surface deposits (alluvial).			Upper Cambrian (Potsdam) sandstone.	
	1.	2.	3.	4.	5.	6.	7.	8.
Depth of well.............feet..	....	....	....	18	14	48	140	400
Silica (SiO_2).....................	8.9						11.9	Undet.
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$).................	1.7	1.4	2.4	5.9	5.6	3.7	2.2	Undet.
Calcium (Ca)....................	21.7	5.7	19.5	18.9	35.9	14.1	53.6	43.5
Magnesium (Mg).................	11.0	.7	6.9	5.6	6.4	3.1	30.0	21.1
Sodium and potassium (Na.+K)	4.7	6.7	6.2	5.5	5.6	7.8	.9	15.7
Carbonate radicle (CO_3).........	64.1	18.2	51.8	22.3	74.7	22.7	146.9	116.
Sulphate radicle (SO_4)...........	3.5	....	2.1	42.4	4.0	24.5	12.1	11.9
Chlorine (Cl).....................	4.8	.9	1.2	.9	....	1.3	1.4	16.3
Total dissolved solids.........	120.	34.	90.	102.	132.	77.6	259.	224.

1. Red Cedar river at Menomonie. Chemist, G. M. Davidson, Sept. 26, 1912.
2. Meridean Spring at Meridean. Chemist, C. M. & St. P. Ry. Co., Nov. 22, 1891.
3. Downsville Spring at Downsville. Chemist, C. M. & St. P. Ry. Co., Nov. 30, 1891.
4. Railroad well at Meridean. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 22, 1891.
5. Railroad well at Caryville. Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 2, 1892.
6. Railroad well at Red Cedar. Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 3, 1892.
7. Railroad well at Weston. Analyst, G. M. Davidson, C. & N. W. Ry. Co.
8. City well, Menomonie. Analyst. Chemist, C. M. & St. P. Ry. Co., Dec. 5, 1903.

EAU CLAIRE COUNTY

Eau Claire County, located in the northwestern part of the state, has an area of 620 square miles and a population of 32,721. About 73.1 per cent of the county is in farms of which 62.2 per cent is under cultivation. About one-third of the county, northeastern part, is sparsely settled.

SURFACE FEATURES

The surface of Eau Claire County is quite uneven and hilly over most parts of the county, being typical erosion topography developed in the sandstone formation. A quite level valley bottom tract lies northeast of Augusta along the Eau Claire river. Altitudes generally range

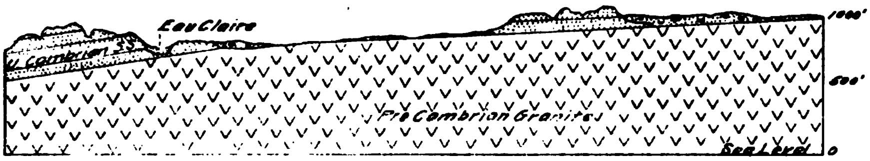

Fig. 35.—Geologic section, east-west, across northern Eau Claire county.

from 800 to 900 feet along the valley bottoms of the Chippewa and Eau Claire rivers to 1,100 and 1,200 feet upon the summits of the sandstone divides. The soils along the Chippewa and Eau Claire rivers are sands and sandy loams. On the uplands sandy loams and silt loams prevail.

GEOLOGICAL FORMATIONS

The outcropping rock formations are the Pre-Cambrian granite rocks along the rivers and streams in the northeastern part, and the Upper Cambrian (Potsdam) sandstone over the remaining portion. Alluvial sand and gravel is a widespread formation, along the Chippewa and Eau Claire rivers, and principal tributaries. Glacial drift, in thin deposits, of one of the early drift sheets, is distributed over the entire county with the exception of the southwest corner, which is driftless. Deposits of loess are common over the uplands in the southwestern part. The geological structure of the county is illustrated in the cross section, fig. 35.

The thickness of the surface formations, consisting mainly of the alluvial filling in the valley, is variable, but probably reaches a maximum of 200 to 250 feet in the deepest parts of the filled valleys. The alluvial formation at Altoona is at least 168 feet thick. The thickness of the rock formations is also variable on account of the extensive erosion of the strata. Some of the highest divides in the southwestern part of the county are capped with thin beds of limestone, which may belong to the Lower Magnesian formation. It is only in these highest upland ridges that the complete section of the Upper Cambrian sandstone is preserved. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Eau Claire County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Upper Cambrian (Potsdam) sandstone	0 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The chief water-bearing strata are the sandstone in the uplands and the alluvial sands and gravels in the valley bottoms. Both these formations are quite porous and furnish abundant supplies. In general a common water level prevails, approximately on a level with the flowing streams of the immediate locality, to which the farm wells must be drilled in order to secure an abundant supply. Occasionally shale beds within the Potsdam sandstone and lying above the general water level develop an impervious basement for the accumulation of sufficient ground water to supply shallow open dug wells. The wells in the valley bottoms are usually from 50 to 100 feet deep, while those on the sandstone uplands are often from 100 to over 200 feet to water.

SPRINGS

Springs are located along the stream valleys where there are outcropping beds of sandstone. Several large springs of this type occur along the Chippewa river below Eau Claire.

WATER SUPPLIES FOR CITIES AND VILLAGES

Eau Claire.—Eau Claire, situated at the junction of the Eau Claire and Chippewa rivers, has a population of 18,310. The city is located on terraces of river gravel and sand, with the underlying Upper Cambrian (Potsdam) sandstone exposed in many places along the river and on the hills back of the city. The city water supply is from a system of 100 wells, 40 feet deep, six inches in diameter, located about 2 miles above the city near the Chippewa river. The supply is furnished by the Eau Claire Water Co.,[1] and the source of supply has been changed several times. It was originally taken from springs, but on account of the insufficient quantity was changed to the Chippewa river, being filtered and treated with chemicals for purification. The river water being unsatisfactory, the source was changed back to the springs supplemented by ground water supply from 100 wells in the gravel. The water has a low mineral content and a small amount of organic matter, except in summer, on account of the presence of algae. The average daily pumpage is about 2,000,000 gallons. There are 2,922 service connections, about 80 per cent of the population being supplied. The city sewage, without purification, empties into the Chippewa river. Cess pools are allowed. Private wells are from 20 to 140 feet deep, depending upon elevation above the river. Granite lies at a depth of 82 feet (also reported 108 feet) at the Brewing Company well, the elevation of the surface of the well being about 790 feet above sea level.

The city water supply of Eau Claire is said to be not wholly satisfactory, though geological conditions here are very favorable for securing an abundant supply of good water, low in mineral content.

Augusta.—This city, situated on Bridge Creek, has a population of 1,405. The city water supply is obtained from two wells 20 feet deep, in sand and gravel. Private wells are from 10 to 20 feet deep usually. No sewage system is installed. About 35 per cent of the houses are connected with the water supply system.

Fairchild.—This village has a population of 678. The water supply if from relatively shallow wells 20 to 40 feet deep, in sand and the sandstone formation.

Altoona.—Altoona, a village of 821, has no public water supply. The village is located on a sandy alluvial terrace, and the private wells are generally from 20 to 60 feet deep, in sand, gravel, and sandstone. The well of Aug. Rahn is a 4-inch driven well, 168 feet deep, through 80 feet of sand, then clay, and then through gravel and sand.

[1] Changed in 1911 to a municipal system.

QUALITY OF THE WATER

Only five analyses of the water supplies of Eau Claire County are available. The water of the Eau Claire spring at Eau Claire, the source of supply being the sandstone, is very soft water. The Chippewa river water near Eau Claire is soft water. The city water supply at Augusta, obtained from the surface sand, is a hard water of moderate mineral content. The other waters analyzed are soft waters. The water throughout the county is very probably either low or moderate in mineral content. The water supply at Augusta is relatively high in chlorine and may possibly be contaminated.

The series of mineral analyses of water of the Chippewa river, samples taken at the Shawtown bridge, extending throughout an entire year, 1906–7, is given on page 213. The series of analyses illustrates the variation in chemical character of the river water at various intervals, the river water being more highly mineralized at low water stages than at high water stages.

The water of the spring, analyses No. 2, of the table, contains 0.67 pounds of incrusting solids in 1,000 gallons, and that of the city water works in Augusta, No. 4, contains 1.13 pounds in 1,000 gallons.

Mineral analyses of water in Eau Claire County.

(Analyses in parts per million.)

	River.	Springs.		Surface deposits.	
	1.	2.	3.	4.	5.
Depth of well .... feet..	....	....	....	19	168
Silica (SiO_2)	12.	17.1	....	9.7	24.6
Aluminum and iron oxides (Al_2O_3+Fe_2O_3)	....	.6	2.6	....	.3
Iron (Fe)	0.2	....	....	....	....
Calcium (Ca)	13.	14.7	10.2	27.0	12.1
Magnesium (Mg)	4.7	5.3	3.7	2.3	4.6
Sodium and potassium (Na+K)	8.1	7.8	8.1	12.6	8.3
Carbonate radicle (CO_3)	....	23.6	33.5	45.	14.2
Bicarbonate radicle (HCO_3)	48.	....	....	....	....
Sulphate radicle (SO_4)	14.	25.0	.5	41.	29.6
Chlorine (Cl)	1.1	7.7	1.3	19.4	9.2
Nitrate radicle (NO_3)	.6	....	....	....	....
Organic and suspended matter	3.7	17.5	....	....	22.6
Total dissolved solids	90.	101.	60.	167.	103.

1. Chippewa River near Eau Claire, mean of 35 analyses, U. S. Geol. Sur. W. S. P. No. 236, p. 55, 1906–7.
2. Spring in bank of Eau Claire River near Altoona. Analyst, G. M. Davidson, Nov. 6, 1911.
3. Eau Claire Spring at Eau Claire. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 27, 1891.
4. Well of city water works, Augusta. Analyst, G. M. Davidson, May 24, 1900.
5. Well of August Rahn, Altoona. Analyst, G. M. Davidson, Nov. 6, 1911.

FLORENCE COUNTY

Florence County, located in the northeastern part of the state, has an area of 498 square miles, and a population of 3,381. Only about 9.2 per cent of the county is laid out in farms, of which 29.1 per cent is under cultivation.

SURFACE FEATURES

Florence County is a plain with minor undulations of drift hills and ridges of crystalline rock. The main drainage line is the Pine river, flowng east through the central porton. The Menominee river and the Bois Brule river are on the eastern and northern boundary. Important lakes are Long lake and Fay lake in the western part, and Spread Eagle in the eastern part. The elevation above sea level is generally between 1,000 and 1,500 feet. The soils are mainly sandy loams in the eastern part and silt loams in the central and western part.

GEOLOGICAL FORMATIONS

The geological formations consist of Pre-Cambrian crystalline rocks overlain by glacial drift . The crystalline formations contain iron ore deposits, which are being mined in the vicinity of Florence and Commonwealth. The glacial drift is of variable thickness and very generally covers the crystalline rock, except in the eastern portion. See Fig. 23.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizon is the surface formation of drift, containing numerous beds of sand and gravel, in which an abundant supply of good water can be obtained. The massive rock of the crystalline formation, such as the granite and greenstone, contain only a small amount of water, but the soft and schistose rocks, such as the iron ore formation and associated slates, usually contain an abundant water supply, as shown by the large volume of underground waters in the iron mines.

WATER SUPPLIES FOR CITIES AND VILLAGES

Florence.—Florence, the county seat, has an estimated population of 1,500. It is located on the site of iron mines, near Fisher Lake, at an el-

evation of 1,200 feet. The city water system obtains its supply from the lake through a 10-inch intake extending 200 feet from the shore. The supply is used for fire and domestic service but is not used for drinking. The average daily pumpage is 75,000 gallons. The drinking water is mainly from wells 12 to 28 feet deep in the sandy and gravelly drift, and caution should be observed in using such well supplies as they are likely to be contaminated.

QUALITY OF THE WATER

Only two analyses of the water of Florence County are available; that of the water of Long Lake and that of a deep mine water at Florence. The water of Long Lake is hard water of low mineral content. The water in the surface formation, and most of the crystalline rocks, is likely to be soft or hard waters low in mineral content throughout the county. Water obtained from graphitic slates, associated with deep iron ore deposits, may, however, show a high content of mineral matter, and may be even salty in places, as illustrated by the analysis of the mine water described below.

Mineral analyses of water in Florence County.

(Analyses in parts per million.)

	Lake.	Pre-Cambrian graphitic schist.
	1.	2.
Depth of well ... feet	......	2,075
Silica (SiO_2)	8.0	......
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	.5	......
Calcium (Ca)	18.1	1,270.
Magnesium (Mg)	8.8	987.
Sodium and potassium (Na+K)	5.0	4,494.
Carbonate radicle (CO_3)	48.9	14.
Free carbonic acid	......	416.
Sulphate radicle (SO_4)	2.1	43.
Chlorine (Cl)	7.7	11,991.
Organic matter	20.2	......
Organic and volatile matter	......	3,722.
Total dissolved solids	99.	18,799.

1. Long Lake. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Oct. 5, 1907.
2. Water from diamond drill hole in Florence Iron Mine. Analyst, Bird Archer, Compound Co, 1910.

SALT WATER IN FLORENCE MINE

A chloride water very similar to that from a flowing well near Osceola in Polk County was recently struck in drilling a deep hole in the

Florence Iron Mine. The analysis of this water made by the chemist of the Bird Archer Compound Co. in 1910 stated as salt compounds in grains per gallon, (see also the above county table) is as follows:

Analysis of salt water from Drill Hole 95 9th Level, Florence Mine.

	In grains per gallon.
Organic and volatile matter	299.125
Sodium chloride	666.159
Calcium carbonate	1.238
Calcium sulphate	3.572
Calcium chloride	200.998
Magnesium chloride	225.780
Free carbonic acid	24.324
Total	1,421.196

The description of the source of this chloride water furnished by Mr. O. W. Wheelwright is as follows:

"This water is an artesian flow from a diamond drill hole drilled vertically from the 9th level of the Florence Mine to a depth of 1,494 feet. The 9th level at this point is 581 feet below the surface making the bottom of the hole approximately 2,075 feet from the surface. It is not known that this water flowed from the hole before its completion. The work was completed on June 15, 1910, and the water is still flowing (Dec. 21, 1912) at the rate of probably 20 gallons per hour.[1] The material crossed by the diamond drill hole was ore and iron formation to a depth of 150 feet and black graphitic slates and pyritic cherty carbonates for the remainder of the distance. The hole still gives off considerable quantities of gas which I assume to be marsh gas. It comes up in such quantities that the water oozing over the top of the casing has the appearance of violently boiling water. The gas burns with a slight blue flame and has a tendency to explode when slightly mixed with air and ignited.

"The water has a very distinctly saline taste. So far as I am aware there is nothing unusual about the ordinary mine water of the Florence Mine. I have drunk water from horizontal drilled holes on the 7th level without tasting anything unusual."

Somewhat similar chloride waters containing much calcium chloride have been observed in deep wells and mines in other parts of the Lake Superior region.[2]

[1] It is reported, Jan. 23, 1915, that the water has ceased to flow, but gas still issues from the pipe.

[2] See Data of Geol. Chemistry, U. S. Geol. Survey Bulletin 330, p. 144.

The high content of organic and volatile matter and free carbonic acid in the Florence mine water appears to be unusual. These constituents are very probably derived from solution of minerals in the graphitic and pyritic slates with which the waters come in contact while imprisoned under high pressure.

Fond du Lac County

Fond du Lac County, located at the south end of Lake Winnebago, in the eastern part of the state, has an area of 720 square miles, and a population of 51,610. About 95.8 per cent of the county is in farms of which 72.5 per cent is under cultivation.

SURFACE FEATURES

The surface of Fond du Lac County is usually gently sloping throughout, the notable exception being the relatively steep escarpment of limestone east and southeast of Lake Winnebago. The land is also quite undulating in the vicinity of Ripon in the northwestern corner of the county, and ridges of limestone are also abundant in the eastern part in the area of the Niagara limestone. A belt of hummocky drift hills trends north and south across the western part of the county. The central and northern part of the county is drained by streams flowing northward into the south end of Lake Winnebago, and the eastern part by streams flowing eastward into Lake Michigan, the southern part by streams flowing south into the Rock river, and the western part by streams flowing west into the Fox river.

The surface of Lake Winnebago is 746 feet above the sea, about 166 feet above Lake Michigan. The general elevation of the upland divides is 1,000 to 1,150 feet with some of the highest ridges in the eastern part of the county rising to 1,150 and 1,200 feet. The limestone escarpment east of Fond du Lac rises abruptly 150 to 250 feet above the low land to the west, but the usual range in elevation of upland ridges and adjacent valleys is between 100 and 150 feet.

GEOLOGICAL FORMATIONS

The geological formations are the same as those of Dodge county and range from the Lower Magnesian limestone in the northwest corner of the county up through the St. Peter sandstone, the Galena-Platteville

(Trenton) limestone and the Cincinnati shale to the Niagara limestone, in the eastern part of the county. The county is usually covered with a variable thickness of glacial drift. Red lacustrine clay and silt overlying sand and gravel beds occupy the depression about the south end of Lake Winnebago.

As shown on the geological map, Plate 1, the bed rock of most of the central and western part of the county is the Galena-Platteville (Trenton) limestone. Along the east side of Lake Winnebago and continuing southward are the prominent limestone bluffs, the Niagara escarpment, east of which the bed rock is the Niagara limestone formation. The geological structure is illustrated in Fig. 36.

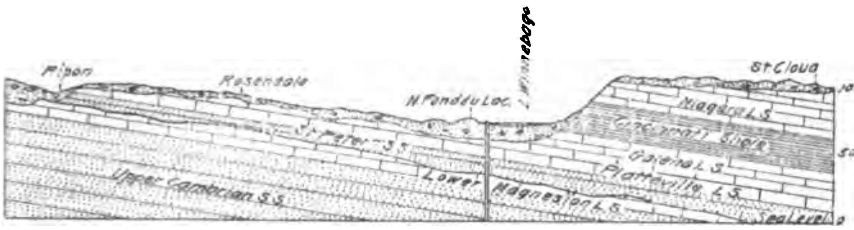

Fig. 36.—Geologic section, east-west, across northern Fond du Lac county.

The thickness of the surface formation of glacial drift, lacustrine and alluvial deposits, is variable between wide limits on account of the very uneven surface upon which it is deposited. The greatest thickness probably occurs in the pre-glacial valleys, where the filling may reach 300 to 350 feet. Upon the inter-stream area the usual thickness of the surface deposits is between 50 and 100 feet. The thickness of the rock formations is also variable on account of the extensive erosion of the strata. The complete thickness of any formation is preserved only where protected by the next overlying formation. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Fond du Lac County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone	0 to 400
Cincinnati shale	0 to 250
Galena-Platteville (Trenton) limestone	0 to 250
St. Peter and Lower Magnesian	0 to 250
Upper Cambrian (Potsdam) sandstone	300 to 600
The Pre-Cambrian granite	......

PRINCIPAL WATER-BEARING HORIZONS

All of the geological formations are drawn upon for water supplies, but the most important water-bearing horizons for the deep wells are the sandstone strata underlying the Galena-Platteville (Trenton) limestone formation. The sandstone strata comprise the St. Peter and Upper Cambrian (Potsdam) formations, as well as some sandstone of the Lower Mangesian. As illustrated at Fond du Lac and Waupun, there is apparently much St. Peter sandstone and shale beds in the usual place of the Lower Magnesian limestone rock.

The rock formation immediately underlying the surface deposits of glacial drift and stratified sand and clay is limestone throughout the county, except in deeply filled valleys along the Fox river, either the Lower Magnesian, the Trenton, or the Niagara, and these limestone formations furnish an abundant supply in common shallow wells in the rural districts within the area of their respective outcrops. In the valleys the water level is near the surface, and even upon the gently sloping uplands it is usually less than 100 feet below the surface. Relatively impervious strata, at, or near the junction of the several geological formations tend to hold up the water level in the upland areas. The impervious Cincinnati shale formation, lying below the Niagara limestone, and above the Galena-Platteville (Trenton) limestone, in the eastern and southeastern part of the county, exerts an appreciable influence on the maintenance of the water level within the overlying Niagara formation, as illustrated at the St. Lawrence College well at Mt. Calvary, the water level in which dropped from 90 feet to 110 below the surface, after passing through the shale into the underlying Trenton limestone and the St. Peter sandstone.

SPRINGS

Springs are common in Fond du Lac county on low ground within the general outcrop area of the Cincinnati shale. These springs are especially abundant along the base of the escarpment of Niagara limestone east and southeast of Fond du Lac. The springs in Taycheedah are especially important. The shale or clay is an impervious stratum and above it lies a varying thickness of fissured Niagara limestone, through which the water descends till its progress is arrested by the shale from the surface of which it flows out wherever opportunity offers. The springs may issue either from the shale directly or from the overlying surface deposits of drift on lower ground after flowing some dis-

tance underground along the surface of the shale under the drift. In some instances, also, the springs issue from the overlying Niagara.

There are important springs also which issue from the horizon at the junction of the St. Peter sandstone and the overlying Trenton limestone in the western part of the county, as illustrated by the springs at Ripon, some of which furnish the city water supply.

FLOWING WELLS

In number and variety of source, the flowing wells of Fond du Lac county are of much importance and interest. The flows are obtained from both the surface deposits and the underlying rock strata. Around the south end of Lake Winnebago, the flows are obtained from sand and gravel beds under the red clays within the surface deposits, and from the limestone immediately underlying the surface deposits. The deeper wells obtain their flows from the various horizons of sandstone strata that underlie the Trenton limestone.

In Fond du Lac and vicinity are a number of flowing wells, the source of the flows being at various depths, from 50 to 512 feet. The strongest initial flow appears to have been that of George Mahall's, one and one-half miles south of the Court House, the well being 335 feet deep, cased 100 feet, having sufficient pressure to raise the water 36 feet above the surface.

The head of the artesian wells in the sandstone in Fond du Lac is quite variable on account of the interference between the wells. The original head of the water from the St. Peter and Upper Cambrian (Potsdam) sandstone was probably 25 to 50 feet above the level of Lake Winnebago, or up to an altitude of about 800 feet above sea level. The original head, however, has been greatly reduced since the earliest wells were put down.

The head of the water in the surface deposits, in the gravel beds underlying the fine lacustrine silts and clays, is generally 10 or 15 feet above the surface at the well mouth. The head in the surface deposits is sufficient to develop flowing wells at an elevation of 100 feet above the level of the lake. The artesian gradient in the surface deposits, however, closely conforms to the land surface, and slopes rapidly down towards the lake.

At Fond du Lac the geological conditions are very like those at Oshkosh. The St. Peter sandstone seems to rest directly upon the Upper Cambrian (Potsdam), as indicated by the fact that in places limestone of the Lower Magnesian horizon is missing. Flows are struck in the Galena-Platteville (Trenton) limestone, in the St. Peter and Lower

Magnesian sandstone, and in the Potsdam sandstone, the latter furnishing the best supply. Several hundred flowing wells have been drilled in and about Fond du Lac. The Fond du Lac Water Company has nine wells of various diameters and varying in depth from 480 to 1,106 feet. Some of the shallower ones get most of their supply from the St. Peter sandstone, while the deeper ones draw on both the St. Peter and the Potsdam formations. Mr. W. H. Masson, Superintendent of the Water Company stated in 1905 that all of the city wells drilled up to that time were packed at a depth of about 275 feet, near the base of the Trenton limestone, so as to shut out all the water except that coming from the St. Peter and Potsdam sandstone, no Lower Magnesian limestone being present. The St. Peter head is not as high as that from the lower strata of the Potsdam, but the exact division between these two sandstones can not be definitely given.

All the old wells reported by Chamberlain in the Geology of Wisconsin, Vol. II, 1873-1877, have been abandoned. Mr. Wild's fountain was pumped up to a few years ago when it gave out entirely, presumably due to the giving way of the casing. It is unfortunate that the old wells should be neglected for every leak due to rusted casing, or overflow will help to destroy the favorable artesian conditions. If these old wells could be permanently plugged before allowed to cave in much leakage would thus be obviated. The neglect of these wells if continued will in time destroy the usefulness of the artesian basin. In order to get the strongest flows, it is necessary to shut off the limestone by packing or casing to avoid any leakage that may occur in this formation. It has been found by the Superintendent of the County Asylum that ordinary iron pipes last about 15 years. At the end of that period the pipes are so corroded that the water leaks out and will not rise to the surface. In many places it requires only half as many years to produce these conditions. In many cases complete renewal of casing will restore the full head.

The common source of water supply of the town of Oakfield is the drift. The flowing wells are found principally in Sec. 9, 14, 15, 16 and 17, where they occupy an extensive depression, stretching northeastward to Fond du Lac. These wells average about 30 feet in depth, have small flows, low pressure, and draw their water from seams of sand and gravel between beds of clay. The older wells, drilled early in the sixties, have, in some cases, ceased flowing because they are choked or filled with sand. Some of these flows have been recovered by pumping. Hundreds of flowing wells have been drilled within this basin.

The logs of some of the flowing wells are shown in the following sections:

Section of J. Kauffmann's well, T. 14 N., R. 17 E., Sec. 18.

Formation.	Thickness.
	Feet.
Surface deposits	56
Shale	100
Limestone	100
Total	256

Section of C. Wherton's well, T. 14 N., R. 16 E., Sec. 12.

Formation.	Thickness.
	Feet.
Clay and sand	60
Sand	10
Shale	100
Limestone	100
Total	270

Section of S. C. Stanchfield's well.

Formation.	Thickness.
	Feet.
Red clay	45
Blue clay, with sandy layer	55
Total	100

Between Fond du Lac and Brothertown, along the shore of Lake Winnebago, the wells are much deeper than those south of Fond du Lac, many having penetrated three water-bearing gravel seams. As a rule the deeper horizons have the strongest flows.

North of Calumet, on the east side of the road, on rather high ground, a well showed the following strata:

Section of flowing well in surface formation near Calumet.

Formation.	Thickness.
	Feet.
Red clay	39
Fine gravel	14
Blue clay	5
Coarse gravel	2
Blue clay	22
Coarse gravel	10
Blue clay	40
Coarse gravel	10
Total	142

East of Calumet flows have been obtained two and one-half miles east of Lake Winnebago, at least 100 feet above lake level. That these wells draw their supply from the same gravel seams is indicated by the way the wells interfere with each other. Near Peebles Corners, a well was put down on low ground and immediately took the water from flowing wells on the higher elevations, and lowered the heads in many of the wells that did not flow.

At Winnebago Park, east of the lake, a large number of flowing wells have been drilled near the lake and only 5 to 8 feet above the lake level. The water rises only 1 to 5 feet above the surface. The drop in head toward the lake is very rapid, showing that the water finds escape into the lake, otherwise the head at or near lake level would be much higher, as indicated by the much higher heads on higher ground one-half mile to two miles farther east. The terminal escape of the water into the lake is also shown by the increase in head during high-water along the east shore of the lake and vice versa. The rapid drop in artesian head down the slope is not confined to this locality, but has been generally observed at other places. The water, in places, may merely seep into the lake, and thereby only partially reduce the head.

WATER SUPPLIES FOR CITIES AND VILLAGES

Fond du Lac.—The population of Fond du Lac is 18,797. The city has a water supply and sewage system. The sewage system is supplied with septic tanks and contact beds, and the effluent is emptied into the Fond du Lac river. The water supply is obtained from nine artesian wells 480 to 1,106 feet deep, connected with a large reservoir. One test[1] well was put down to a depth of 1,106 feet and penetrated granite either 46 or 54 feet. This did not yield enough more water in comparison with the 750 foot wells to pay for the increased depth. The wells, now used, are four 10-inch wells, 724, 760 and two 784 feet deep, and four 6-inch wells, one 756 feet and two 600 feet and 480 feet deep. The ten inch wells were put in last; one is located at the pumping station, and two, 1,000 and 2,000 feet north of the station. The 6-inch wells are located on the station lot and all interfere with one another, while the two to the north do not affect those at the station or one another. The constant increase in the number of private wells put down, and the heavy draft upon these city wells are responsible for the gradual reduction in the yield of the underground supply at Fond du Lac.

An electrically driven deep-well propeller pump has been installed

[1] W. G. Kirchoffer, Bull. Univ. of Wis. No. 106, p. 215.

in one of the 10-inch wells having a capacity of 700 gallons per minute, which will lower the water to the bottom of the pump, 90 feet in 10 hours. The water-works wells have taken the water from some of the private artesian wells and decreased their flows. The average daily pumpage is about 1,200,000 gallons. There are 3,256 service connections. The capacity of the impounding reservoir is 2,500,000 gallons.

The log of the 1,106 foot city well at Fond du Lac is as follows:

Log of well of the Fond du Lac Water Company.

Formation.	Thickness.
	Feet.
Pleistocene:	
Drift (red clay and sand)	106
Galena-Platteville (Trenton):	
Limestone	175
St. Peter (and Lower Magnesium):	
White sandstone	200
Upper Cambrian (Potsdam):	
Dark red sandstone	19
Coarse sand	25
Fine sand	75
White sand	100
Yellow sand	40
Coarse calcareous sand	30
Various red sand	290
Archean:	
Granite	46
Total depth	1,106

The log of the well of Emil Thun, drilled by P. Roughen, 5 miles south of Fond du Lac, showing a considerable thickness of the Cincinnati shale is as follows:

Logs of well of Emil Thun, 5 miles South of Fond du Lac.

Formation.	Depth.	Thickness.
	Feet.	Feet.
Pleistocene:		
Soft red calcareous clay	0- 12	
Soft bluish calcareous clay	12- 30	
Brownish blue calcareous clay	30- 50	
Same as last	50- 70	
Same as last	70- 90	
Same as last	90-101	
Brownish sand (and gravel), some hard water	101-106	
Brownish (blue) hard clay	106-125	
Gray calcareous clay	125-140	
Same	140-156	
Same, hard and dry	156-170	170
Cincinnati Shale:		
Light brownish gray shale, slightly calcareous. Cased through this bed	170-179	
Dark brownish gray, gritty calcareous shale	179-190	
Gray (brownish) shale	190-290	
Same as last	200-220	
Same as above, sticky	220-440	
Same as above, soft and tough	240.255	85
Galena, Platteville (Trenton limestone:		
Brownish limestone	255-264	9
Total depth		264

Ripon.—The population of Ripon is 3,739. The city has a water supply system owned by the Ripon Light and Water Co. A city sewage system is installed. The average daily pumpage of water is about 300,000 gallons. There are 816 service connections. About 80 per cent of the houses have water connections, and 40 per cent have sewer connections. Filter beds are used in disposing of the sewage. Many private wells in the city are from 15 to 20 feet deep.

The city water supply[1] is obtained from three wells, varying in diameter from 20 to 30 feet each about 18 feet deep, and located about 20 to 30 feet apart. These wells were installed in 1889, and the water of the wells is doubtless furnished by the water-bearing gravel of this section, which for the most part is nearly horizontal, and in places only 10 or 12 feet below the surface of the ground.

When the wells were first installed an analysis showed the water to contain 5.8 parts per million of chlorine. Later it was found that the chlorine content varied from 15 parts to 23 parts per million. This increase in chlorine was partly accounted for by the presence of a hide house about 450 feet from the wells, and above the strata furnishing the water supply. When the hide house was cleaned up the chlorine content fell to 12 parts per million. It is Prof. Gilman's opinion that the normal chlorine content of the water in this section is about 3 or 4 parts per million.

During the summer of 1911 a collecting basin was constructed about a mile east of the wells, and a pipe laid to conduct the water by gravity to the wells. This collecting basin acts as a reserve supply, and is about 4 feet deep and 3 feet wide, extending along for several yards in the gravel. Since this has been connected with the original supply the hardness of the city water has been diminished and the water improved in other ways.

Waupun.—The population of Waupun is 3,362. The city has a water supply and limited sewage system. The water supply is obtained from artesian wells. The average daily pumpage is 114,000 gallons. A sewage system is provided for on only one street, and this, without treatment, empties into the west branch of the Rock river. About 35 per cent of the houses are connected with the sewage system. About 20 per cent of the families have cess pools.

[1] Data furnished by Prof. C. F. Gilman.

The first city well, No. 1, elevation of curb 905, A. T., was drilled in 1892, 6 inches in diameter, 700 feet deep, cased 150 feet, failed to flow, water standing 20 feet below the surface. The second well. No. 2, on lower ground, 883 feet A. T., 6 inches in diameter, 755 feet deep, cased 140 feet, flowed at the surface. The third well, No. 3, drilled in 1897, same level as No. 2, 10 inches in diameter, 965 feet deep, cased 140 feet, also flowed at the surface. The two latter wells now flow 4 feet below the surface into a reservoir, from which the water is pumped for all city purposes. In well No. 2 is an air lift of 110 feet, which is used in case of shortage in water. While pumping No. 2, the other well, No. 3, is shut off to prevent water flowing into it, for lowering water in No. 2 draws the water down in No. 3, which is only 130 feet west. The city well No. 4 was drilled in 1904. There are many private wells in the city from 20 to 40 feet deep. At the State Prison, the water supply is obtained from a deep well drilled in 1902, 6 inches in diameter, 755 feet deep. The logs of the deep city well No. 3, and of the State Prison well, are as follows:

Logs of wells at Waupun.

Formation.	City well No. 3. Thickness.	State prison well Thickness.
Pleistocene.	Feet.	Feet.
Drift	13	55
Galena-Platteville (Trenton).		
Limestone	62	52
St. Peter Lower Magnesian and Potsdam		
Sand rock	101	103
White sandstone	220	140
White and pink sandstone	....	103
Red sandstone	....	12
White calcareous sandstone	189	95
White sandstone	80	140
Colored sandstone	300	55
Total depth	965	755

The city well No. 4 drilled in 1904, samples of which are on file in the State University, and in which limestone in the Lower Magnesian horizon was penetrated, has the following log:

Log of Waupun city well No. 4.

Formation.	Thickness.
	Feet.
Surface formation	3
Galena-Platteville (Trenton) limestone	157
St. Peter sandstone	125
Lower Magnesian limestone	41
Upper Cambrian (Potsdam) sandstone	424
Pre-Cambrian, soft feldspathic rock	50
Total	800

Mount Calvary.—East of Fond du Lac, at Mount Calvary, a deep well was drilled for the St. Lawrence College. The altitude of the curb is 1,060 feet. The water from the first limestone rose within 90 feet of the surface, but on passing through the shale into sandstone the water dropped down to 110 feet of the surface. The following record was furnished by the President of the college, who has a complete set of samples in his possession.

Log of St. Lawrence College Well, Mount Calvary.

Altitude of Curb 1060.

Formation.	Thickness.
	Feet.
Glacial drift:	
Clay, sand, boulders	138
Niagara limestone:	
Dark, light, and gray limestone	231
Cincinnati shale:	
Blue, and green shale	111
Trenton limestone:	
Blue and buff limestone	155
St. Peter, Lower Magnesian and Potsdam:	
White and colored sandstone with beds of shale	541
Archean:	
Granite	44
Total depth	1220′

Brandon.—The population of Brandon is 684. The water supply is obtained from private wells. The dug wells are from 20 to 40 feet deep, and the drilled wells from 50 to 100 feet deep.

QUALITY OF THE WATER

The waters of Fond du Lac county, as shown in the table of analyses, are generally either hard or very hard. The water from the deep wells, drawing their supply from the underlying St. Peter and Potsdam sandstone, appear to be less mineralized on the average than the waters derived from the Galena-Platteville (Trenton) limestone, the Cincinnati shale and the surface deposits. The only soft water analyzed is that from the Potsdam sandstone, No. 24. Very hard waters, it will be noted, occur in shallow wells in surface deposits at Ripon and at Brandon. The hardest water is that from the well 57 feet deep at Oakfield, the source of the supply apparently being the Cincinnati shale. Very hard waters of this sort, and often of a saline character, may be characteristic of the Cincinnati shale formation in other parts of eastern Wisconsin.

With one exception, No. 24, among the waters analyzed, calcium is the predominating basic constituent. In the surface waters and waters from the surface deposits, magnesium is very generally more abundant than sodium, but in the hard rock formations the sodium generally predominates over magnesium. Most of the waters are carbonate waters although sulphates are important in many of the waters. Sulphate is more abundant than carbonate in three of the deep well waters and in one of the shalow well waters.

The chlorine content is realtively high in flowing wells from deep seated sources in the sandstone and other formations and is very evidently therefore a naturally abundant constituent of the deep underground water.

The city artesian supply of Fond du Lac, Analysis No. 28, of the table of mineral analyses, contains 2.85 pounds of incrusting solids in 1,000 gallons; the city water supply of Ripon, Analysis No. 13, contains 3.31 pounds in 1,000 gallons; and the water of the hotel well at Oakfield, Analysis No. 19, contains 5.47 pounds in 1,000 gallons.

Mineral analyses of water in Fond du Lac County.

(Analyses in parts per million.)

	Lakes.			Springs.		Surface deposits.	
	1.	2.	3.	4.	5.	6.	7.
Depth of well.........feet..						18 ft. and river.	18 ft. and river.
Silica (SiO_2)	13.7	17.8	1.7	10.8	10.6		
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$..............	0.7	1.0	1.0	1.0	2.5	4.6	1.2
Calcium (Ca)................	34.8	54.4	61.9	63.0	74.9	43.8	90.0
Magnesium (Mg)............	18.3	39.8	35.3	33.5	41.2	32.4	49.5
Sodium and potassium (Na+K)..................	1.7	4.4	4.2	3.2	10.0	10.5	1.2
Carbonate radicle (CO_3)	100.6	121.5	169.1	170.9	165.9	142.8	198.6
Sulphate radicle (SO_4).......	9.8	96.5	17.9	9.5	85.8	17.5	92.0
Chlorine (Cl)	3.1	4.3	6.7	4.8	10.8	6.3	1.8
Organic matter.............	16.1	1.8	60.5				
Total dissolved solids.......	183.	340.	298.	297.	402.	257.	434.

	Surface deposits.						
	8.	9.	10.	11.	12.	13.	14.
Depth of well..........feet..	18	20	40	48	10	18	30
Silica (SiO_2)..................					11.8	23.8	16.4
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)............	5.5	5.6	Undet.	Undet.	1.0	2.9	1.0
Calcium (Ca)...............	156.9	113.4	96.6	114.7	56.6	77.4	130.2
Magnesium (Mg)	66.8	58.7	54.3	64.0	26.8	45.9	50.4
Sodium and potassium (Na+K)................ ...	23.4	70.4	34.4	59.7	4.7	15.9	30.1
Carbonate radicle (CO_3)....	171.1	270.8	203.1	211.6	140.3	200.	162.8
Sulphate radicle (SO_4)......	368.6	94.9	96.9	312.2	18.4	55.2	313.6
Chlorine (Cl)................	32.3	93.2	51.0		7.2	18.2	28.1
Nitrate radicle (NO_3).......			33.1				
Total dissolved solids.......	825.	707.	569.	763.	267.	439.	723.

1. Lake Winnebago near North Fond du Lac. Analyst, G. M. Davidson, Jan. 1905.
2. Mill Pond at Ripon. Analyst, G. M. Davidson, Aug., 1901.
3. Paul's Lake at St. Cloud. Analyst, G. M. Davidson, May 6, 1903.
4. Spring near Creamery at Eden. Analyst, G. M. Davidson, Feb., 1899.
5. Spring at Oakfield water piped into a well. Analyst, G. M. Davidson, June, 1896.
6. Railroad well and Rock River, Waupun. Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 10, 1889.
7. Railroad well and Rock River, Waupun. Analyst, Chemist C. M. & St. P. Ry. Co., May 9, 1901.
8. Well of C. M. & St. P. Ry. at Ripon. Analyst, Chemist C. M. & St. P. Ry. Co., May 10, 1901.
9. Well of the C. M. & St. P. Ry. Co., Brandon. Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 10, 1889.
10. Well of the C. M. & St. P. Ry. Co., Brandon. Analyst, G. M. Prentiss, March 28, 1912.
11. Well of the C. M. & St. P. Ry. Co., Brandon. Analyst, G. M. Prentiss, May 29, 1900.
12. Well of C. & N. W. Ry. Co., St. Cloud. Analyst, G. M. Davidson, Nov. 17, 1905.
13. City Water Supply, Ripon, 3 wells. Analyst, G. M. Davidson, Jan. 22, 1901.
14. Well of C. M. & St. P. Ry., Ripon. Analyst, G. M. Davidson, June 24, 1901.

***Mineral analyses of water in Fond du Lac County*—Continued.**

(Analyses in parts per million.)

	Surface deposits.				Cincinnati shale.	Galena-Platteville limestone.
	15.	16.	17.	18.	19.	20.
Depth of well ....feet..	25	48	....	54	57	80
Silica (SiO_2)		.	13.7	18.4	16.3	14.7
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	3.6	....	....	2.0	1 0	12.3
Calcium (Ca)	76.5	110.0	47.5	231.7	138.7	100.8
Magnesium (Mg)	41.6	61.4	36.5	24.9	78.9	36.6
Sodium and potassium (Na+K)	21.0	51.0	11.3	33.9	94.8	24.8
Carbonate radicle (CO_3)	180.8	244.1	153.1	334.5	374.0	251.6
Sulphate radicle (SO_4)	87.4	180.8	75.	86.4	154.1	28.1
Chlorine (Cl)	11.5	67.6	6.9	75.8	106.8	5.9
Total dissolved solids	422.	664.	344.	808.	965.	475.

	St. Peter and Upper Cambrian (Potsdam) sandstone.							
	21.	22.	23.	24.	25.	26.	27.	28.
Depth of well ....feet..	360	400	350	600	326	....	700	385—756
Silica (SiO_2)	6.6	6.9			....	13.	11.6	10.4
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	Trace	....	1.7	16.2	....	....	1.6	1.0
Aluminium oxide (Al_2O_3)	....	0.9	....	....	....	....	....	....
Iron (Fe)	....	0.1	....	....	....	....	....	....
Calcium (Ca)	68.2	113.4	49.6	17.9	56.5	45.	74 5	92.9
Magnesium (Mg)	27.5	31.7	20.6	16.7	23.	24.	33.2	24.2
Sodium (Na)	39 0	31.9	28.5	30.8	50.	45.	48.7	59.2
Potassium (K)		7.6		26.7	....	....	....	....
Carbonate radicle (CO_3)	128.5	140.5	102.7	86.6	97.	122.	118.4	175.0
Sulphate radicle (SO_4)	98 7	117 0	21.3	118.2	117.6	58.8	128.4	54.9
Chlorine (Cl)	33.5	98.9	28.0	38.7	42.3	45.	68.7	77.1
Organic matter	....	....	....	....	9.9	....	....	....
Total dissolved solids.	402.	549.	252.	302.	386.	353.	485.	496.

15. Well of C. M. & St. P. Ry. Co., Ripon. Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 10, 1889.
16. Well of C. M. & St. P. Ry., Brandon. Analyst, Chemist C. M. & St. P. Ry. Co., May 10, 1901.
17. City Water Supply, Ripon. Analyst, Dearborn Drug & Chem. Co., Aug. 26, 1896.
18. Well of Mr. Botzen, Eden. Analyst, G. M. Davidson, Feb., 1899.
19. Well of Hotel at Oakfield. Analyst, G. M. Davidson, Dec., 1898.
20. Well near C. & N. W. Ry. Co.'s office building, N. Fond lu Lac. Analyst, G. M. Davidson, July 28, 1903.
21. Well of "Soo" R. R., North Fond du Lac. Analyst, G. M. Davilson, Sept., 1901.
22. City well, North Fond lu Lac. Analyst, W. S. Ferris.
23. Well of C. M. & St. P. Ry. Co., Fond du Lac. Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 10, 1889.
24. Artesian well, Fond du Lac. Analyst, A. C. Barry.
25. B. Wild & Co.'s Artesian well, Fond du Lac. Analyst, G. Bode.
26. Wild's Artesian well, Fond du Lac. Analyst, G. Bode, Geol. of Wis., Vol. 2, p. 32, 1877.
27. Flowing well at Fond du Lac. Analyst, Dearborn Drug & Chem. Co., May 22, 1907.
28. City Water Supply from four artesian wells, Fond du Lac. Analyst, G. M. Davidson, June 18, 1895.

Forest County

Forest County, located in the northeastern part of the state, has an area of 1,424 square miles, and a population of 6,782. Only about 3.1 per cent of the county is laid out into farms, of which 21.7 per cent is under cultivation.

SURFACE FEATURES

The county is a gently sloping plain, with undulating hills of glacial drift. Numerous lakes lie in the southern and northwestern parts of the county. The northern part is drained by the Pine and Brule rivers, tributaries of the Menominee; the southeastern part is drained by the Peshtigo river, and the southwestern part by the Wolf river. The elevations above sea level generally lie between 1,300 and 1,600 feet. The soils are generally clay or silt loams and sandy loams.

GEOLOGICAL FORMATIONS

Glacial drift of variable thickness quite generally covers the bed rock of Pre-Cambrian crystalline fromations. The drift, which consists of clay, sand, gravel and boulders, varies in thickness from a few feet to over 200 feet. See the geologic section, Fig. 23.

PRINCIPAL WATER-BEARING HORIZONS

The principal source of the water supply is the surface formation of glacial dirft. An abundant supply of good water can readily be obtained in this formation throughout the county at relatively shallow depths of 20 to 50 feet.

WATER SUPPLIES FOR CITIES AND VILLAGES

Crandon. Crandon, the county seat, has a population of 1,833. It is situated on Lake Matonga, the head of Wolf river. The soil formation is silt loam. No city water system has been installed, but a good supply could be obtained from wells in the drift. Private wells are generally from 10 feet to 30 feet deep in drift. No sewage system has been installed.

QUALITY OF THE WATER

The water of Forest County is either soft or medium hard water, as shown by the analyses of ground water supplies at Wabeno, Laona and Crandon, and also the surface water of the creek at Wabeno. The waters are low in mineral content.

The railroad well at Crandon contains 0.99 pounds of incrusting solids in 1,000 gallons, while that from the well at Wabeno contains 1.22 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Forest County.

(Analyses in parts per million.)

	Creek,	Surface deposits.		
	1	2.	3.	4.
Depth of well.........feet..	....	12	12	41
Silica (SiO_2).........	16.9	9.9	16.8	21.7
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	1.7	2.0	2.2	.8
Calcium (Ca).........	27.3	33.1	32.2	23.2
Magnesium (Mg).........	16.6	13.3	12.9	5.3
Sodium and potassium (Na+K).........	4.4	3.8	9.1	8.9
Carbonate radicle (CO_3).........	81.9	78.2	82.5	85.4
Sulphate radicle (SO_4).........	2.5	8.4	5.5	31.5
Chlorine (Cl).........	4.9	5.9	9.9	13.5
Total dissolved solids.........	156.	155.	171.	140.

1. Creek at Wabeno. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Sept. 13, 1907.
2. Railroad well at Wabeno. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Sept., 1897.
3. Railroad well at Laona. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Sept. 13, 1907.
4. Railroad well at Crandon. Analyst, G. M. Davidson, C. & N. W. Ry. Co., June 3, 1909.

GRANT COUNTY

Grant county, located in the southwest corner of the state, has an area of 1,157 square miles and a population of 39,007. About 92.1 per cent of the county is laid out in farms, of which 59.8 per cent is under cultivation.

SURFACE FEATURES

The surface of Grant county is a deeply dissected upland plain, sloping gently to the southwest towards the Mississippi river. The uplands consist of rather level-topped elevations or ridges. Below

the level-topped uplands are the numerous valleys, those along the minor streams being narrow with slopes gradually rising to the upland areas. The elevation above sea level ranges from a little above 600 feet along the Mississippi river bottoms to 1,000 feet on the level-topped uplands in the southern and southwestern part of the county, and over 1,200 feet on the uplands in the northeastern part. Sinsinawa Mound reaches an altitude of 1,150 feet, about 200 feet above the general level of the surrounding uplands of the southern part of the county. The highest land in Grant county is on the summit of the divide in the

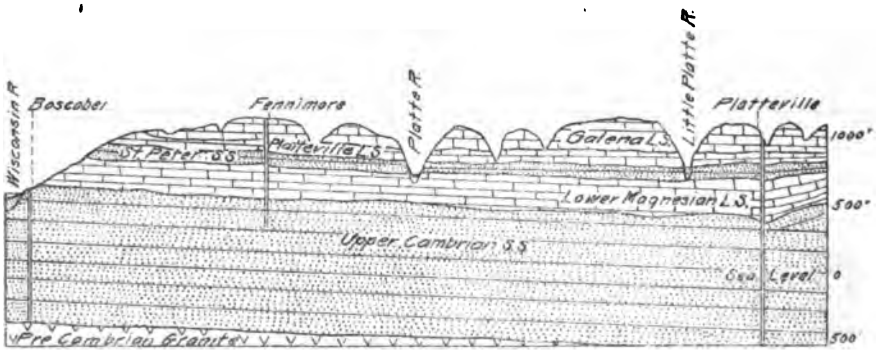

Fig. 37.—Geologic section across Grant County from Boscobel to Platteville.

northern part at Fennimore, Mt. Ida and Mt. Hope, where altitudes over 1,200 feet are reached. Maximum differences in elevations are therefore over 600 feet in the county.

GEOLOGICAL FORMATIONS

The geological formations of the county are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian (Shakopee and Oneota) limestone, the St. Peter sandstone, and the Platteville-Galena (Trenton) limestone. The most common formation, forming the uplands of most of the county is the Galena limestone. The Lower Magnesian limestone occurs mainly along the lower slopes of the valleys and the Upper Cambrian (Potsdam) sandstone occurs only in the valley bottoms of the Wisconsin river and adjacent tributaries. The formations above the Galena, such as the Cincinnati (Maquoketa) shale and the Niagara limestone, occur only on the Sinsiniwa Mounds. Superficial deposits of loess lie over the upland areas, and alluvial sand and gravel is abundant in the valley bottoms. The general geological structure is illustrated in Fig. 37.

The thickness of the alluvial sand and gravel in the valleys of the Wisconsin and Mississippi rivers probably reaches a maximum of 200 to 250 feet. The thickness of the loess on the uplands varies from a few inches up to 10 or 15 feet. Along the Mississippi Bluffs the accumulation of loess, washed down from the uplands, attains a thickness of 50 or 60 feet.

The thickness of the rock formation is variable on account of the erosion of the strata. The complete thickness of a formation is preserved only where it is protected by the overlying formation, as indicated in the cross section, Fig. 37. The formations also vary in thickness to a considerable extent on account of variable conditions at time of deposition. The thickness of the formations underlying the Galena-Platteville in Grant county is apparently much greater than in the region farther north and east, as indicated by the logs of the deep wells at Platteville and Dubuque, indicated in the following sections. While granite is reported to have been struck in the Cassville well at 1,102 feet, this report is doubtful.

The total thickness of the geological formations at Platteville, as interpreted from the strata in the two wells, only a part of the Galena being present on account of erosion, is approximately as follows:

Geological section at Platteville.

Formation.	Thickness.
	Feet.
Galena dolomite, partly eroded	35
Platteville limestone	65
St Peter sandstone	103
Lower Magnesium (Shakopee and Oneota) dolomite	345
Upper Cambrian (Potsdam) sandstone	1,146

The data in regard to the old well was received from the city clerk by Prof. W. W. Daniells in 1897, while the water was being examined, and gives as a total depth of well to granite of 1,714 feet. F. Gray of Milwaukee, who drilled the well, reports that the well is 1,744 feet deep, and that it was finished in red granite for a distance of about 30 feet.

It is of interest to compare the geologic section at Platteville with that at Dubuque, as follows:

General Geologic Section at Dubuque.[1]

Formation.	Thickness.	Elevation of stratum + above, — below sea level.
Galena dolomite to Platteville limestone:	Feet.	Feet.
Dolomite	237	+550
Limestone, bituminous shale, green shale	46	+504
St. Peter sandstone:		
White sandstone, water bearing	58	+446
Prairie du Chien group:		
Dolomites, (Shakopee and Oneota), arenaceous in places, New Richmond sandstone perhaps at 376 feet, with some shaly beds	310	+136
Jordan sandstone:		
Sandstone, water bearing	95	+41
St. Lawrence formation:		
Dolomites and shales; dolomites to sea level, shale, red marls, arenaceous and glauconiferous	179	—138
Dresbach sandstone:		
Sandstone, water bearing	221	—359
Unnamed Cambrian strata:		
Shales	121	—480
Sandstone, water bearing above	768	—1,248

[1] "Underground Water Resources of Iowa." U. S. Geol. Sur. W. S. P. 293, p. 314.

The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Grant County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Niagara limestone (only on Sinsinawa Mounds)	0 to 50
Maquoketa Shale (only in southeastern part of county)	0 to 200
Galena-Platteville (Trenton) limestone	0 to 300
St. Peter and Lower Magnesian formations	0 to 450
Upper Cambrian (Potsdam) sandstone	1000 to 1400
The Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

The water supplies are drawn from all the geological horizons. For deep wells the principal horizons are the St. Peter sandstone and the Upper Cambrian sandstone. The shallow wells in the valley alluvium vary from 10 to 30 feet, while those upon the uplands reach a depth of 100 to 200 feet or more in the Platteville-Galena and St. Peter formations. Springs are common along the valleys at various geological horizons, but mainly at the bottom of the St. Peter, the Platteville and the Galena formations.

While a large part of the county lies far above the level of the Mississippi river on the southwest, and above the Wisconsin river on the north, on account of the relatively impervious strata at or near the bottom of the Galena, the Platteville limestone and the St. Peter sandstone, the underground water table is generally held relatively high, throughout the uplands of the county. As a general rule the water level on the uplands, in the lead and zinc mines, is generally less than 100 feet[1] below the surface. Even upon the high divide in the northern part of the county at altitudes closely approximating 1,200 feet, abundant water is generally found less than 200 feet below the surface. This is well illustrated at Montfort, where the altitudes range between 1,160 and 1,200 feet, the water supply being obtained, either from within the Platteville limestone or at the top of the underlying St. Peter sandstone, at depth of 60 to 200 feet. Over most of the undulating uplands a sufficient supply is obtained from the Galena limestone, which immediately underlies the surface. In some places the water in the Galena is let out by crevices, and in such places it is necessary to drill beyond the ordinary depth.

FLOWING WELLS

Flowing wells from the Upper Cambrian (Potsdam) sandstone occur along the Mississippi river, the water rising to an altitude of 658 feet at Cassville, about 50 feet above the level of the river. At Dubuque[2] artesian wells in the Upper Cambrian sandstone have, at present a head of 40 to 100 feet above the Mississippi river. Artesian flows along the north side of the Wisconsin river are common between Wauzeka and Prairie du Chien, but none are reported along the south side of the river in Grant county. The water in the deep city wells at Boscobel rises to an elevation of 30 to 35 feet above the level of the Wisconsin river adjacent. Going down the river from Boscobel the artesian head should gradually rise to 50 or 60 feet above the level of the Wisconsin, where it joins the Mississippi. The head of one of the earliest artesian wells at Prairie du Chien, Crawford County, was about 100 feet above the level of the Mississippi river.

While no artesian flowing wells are known to occur in the valleys of the Grant and Platte rivers, conditions appear to be favorable for flows in the lower sections of these valleys.

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[1] U. S. Grant, "Lead and Zinc Deposits." Bull. Wis. Survey, No. IX, p. 48.
[2] Lancaster-Mineral Point U. S. Geol. Sur. folio, No. 145, p. 14 and Iowa Geol. Survey, Vol. 21, p. 380.

SPRINGS

Numerous springs occur in the county, most of which have their source at the bases of the St. Peter sandstone, the Platteville limestone, the Galena limestone, and the Niagara limestone. Springs also issue at the shaly layers within the Galena and the Lower Magnesian limestone formations, along the lower slopes of the valleys. Many of the springs are large and furnish an excellent suply of water for domestic use.

WATER SUPPLIES FOR CITIES AND VILLAGES

Platteville.—This city, having a population of 4,452, has a water supply system, the supply being obtained from two deep wells. 1,000 feet and 1,740 feet deep. The average daily pumpage is about 130,000 gallons. A sewage system was installed recently. Sewage is purified by a system of three septic tanks and emptied into the creek. About 60 per cent of the people use the city water.

The city supply until recently was obtained from a 6-inch well 1,714 or 1,744 feet deep. At present the supply is mainly from a new well 1,000 feet deep, 16 inches in diameter for the first 300 feet and 9¼ inches in diameter for the remaining depth. The present city supply is obtained mainly or entirely from the St. Peter sandstone which lies at depth of 100 feet.

The geological section in the new city well (elevation of curb about 900 feet) as interpreted from samples of the new well, and from additional data of the old well, is as follows:

Log of Platteville City Wells.

Formation.	Character of Rock.	Thickness.
		Feet.
Surface	Soil, clay, sand	20
Galena	Hard, gray limestone	35
Platteville	Bluish limestone with fossils	65
St. Peter	White sand	103
Lower Magnesian (Shakopee and Oneota)	Thin limestone	2
	Hard limestone	179
	Sandy limestone	26
	White sandstone	30
	Limey sandstone	10
	Hard limestone	88
	Limestone	12
	Soft limestone	2
Upper Cambrian (Potsdam)	Limey sandstone (Madison beds)	48
	Limey shale (Mendota beds)	43
	White sandstone	162
	Limey sand	83
	Gray limey, sandy shale	10
	Red limey, sandy shale	18
	White and brownish sand	64
	Additional sandstone in old well	714
Pre-Cambrian	Granite	0-03
	Total depth	1,714 or 1,744

Cassville.—The population is 890. This village, located on the Mississippi river, has a city supply obtained from a deep artesian well in the Upper Cambrian (Potsdam) sandstone, which normally has a flow of 16 feet above the surface. Elevation of curb is 642 feet. The well is 6 inches in diameter, is cased 172 feet, has a depth of 1,102 feet, and is reported to have struck the granite at bottom. Only a small portion of the water is used, the remainder flowing into the Mississippi river. There are about 59 houses connected with the city supply.

Lancaster.—The population of Lancaster, the county seat, is 2,329. It is situated upon the divide between tributaries of the Grant and Platte rivers at an elevation ranging between 1,060 and 1,100 feet. The bed rock formation is the Galena limestone. The city water supply is from springs in the limestone, two and one-half miles from the city. The capacity of the springs is 4,000,000 gallons per day. The average daily pumpage is 107,000 gallons. Sewage is treated by septic tank and filtered before it is emptied into the creek. About 75 per cent of the houses are on the water supply system, and about 20 per cent have sewer connections. About 5 per cent of the families have cess pools.

Cuba City.—The population is 967. The water supply is obtained from two 6-inch wells, 133 feet and 225 feet deep in the Galena-Platteville limestone. The water bed is 30 feet below the surface. The average daily pumpage is 21,000 gallons.

Wells along the ridges in the vicinity of Cuba City get their supply from limestone at depths of from 75 to 200 feet. In the valleys many open wells draw their water from the surface soil, and are only 12 to 30 feed deep. Until lately most of the wells in this vicinity obtained their supply from the Galena-Platteville limestone. In recent years, however, the water level has dropped until at present a great many of the wells go down into the underlying St. Peter sandstone formation, and occasionally through the St. Peter into the Lower Magnesian limestone to secure an abundant supply.

Muscoda.—The population is 798. This village located on the Wisconsin river, has a water supply system for fire protection only, obtained from 24 3-inch wells with 5 foot points driven 32 feet into the river sand. Recent reported information indicates that this system has not been utilized for some time. The water supply for domestic purposes is obtained from driven wells 20 to 40 feet deep in sand and gravel..

Boscobel.—This city, population 1,525, is located on the Wisconsin river. A public water supply was installed in 1913, the supply being obtained from a well 700 feet deep and 12 inches in diameter. The altitude of the well curb is approximately the same as at the C. M. & St.

P. Ry. station, 674 feet. The water in the well rises to within 3½ feet of the surface. In a partial test the well furnished 150 gallons per minute in 5 hours, the capacity undoubtedly being much greater. The city reservoir, capacity 100,000 gallons, is located on the hill south of the city at an elevation of 170 feet above the curb. A sewage system is being installed. The sewage is to be treated in septic tanks before beemptied into the Wisconsin river. Water is supplied from private wells 30 to 60 feet deep in the alluvial sand and the underlying sandstone. The well of the C. M. & St. P. Ry. Co. is reported to be 1,000 feet deep, elevation of curb 675 feet, water standing one foot below the surface. The city well in the city park, elevation of curb 690 feet, is reported to be 965 feet deep, the water standing 20 feet below the surface. Both of these wells reach the granite.

The section of the new city well, elevation of curb 674 feet, 12 in. casing down 140 feet, drilled in 1913 is as follows:

Driller's log of well of Boscobel Water Works.

Formation.	Thickness.
	Feet.
1. Surface sand	125
2. Gravel	5
3. Shale	5
4. White sandstone	105
5. Shale	5
6. White sandstone	15
7. Brown sandstone	10
8. White sandstone	65
9. Shale	10
10. White sandstone	165
11. Brown hard sandstone	10
12. White hard sandstone	2
13. Gray sandstone	15
14. White hard sandstone	98
15. Sandstone containing iron pyrite	10
16. White sandstone	40
17. Shale	5
18. White sandstone with coarse sand	20
19. White sandstone with red pigment	5
Total depth	700

As indicated by reported depth to granite in the other deep wells in the city, above referred to, an additional thickness of sandstone of 250 to 300 feet may be expected below No. 19. Nos. 1 and 2 are alluvial formations, and the elevation of the contact between the Upper Cambrian and the Lower Magnesian about 4 miles south of Boscobel is about 860 feet; hence the total thickness of the Upper Cambrian sandstone in this locality is probably about 1,100 feet, about the same as at Platteville.

Fennimore.—The population is 1,159. The city water supply is obtained from two wells, 250 and 800 feet deep. No sewage system is installed.

Montfort.—The population is 558. This village has a water supply system mainly for fire protection, obtained from an 8-inch well, 114 feet deep. Forty-six houses are reported to be connected with the water system. The deeper wells penetrate through the Galena-Platteville limestone into the St. Peter sandstone.

Hazel Green.—Hazel Green, population 621, has a city water supply obtained from a well 190 to 195 feet deep. Only a small per cent of the population use the city supply.

QUALITY OF THE WATER

The water supplies of Grant county are hard waters of moderate mineral content throughout, and quite uniform in composition, as indicated in the following table of mineral analyses. Most of the supplies from the deep wells at Fennimore and Platteville, though such wells reach the Upper Cambrian (Potsdam) sandstone, receive their supply mainly from the St. Peter sandstone. No analyses of water from the Maquoketa shale are available, but water from this shale or immediately associated formation is likely to contain a higher content of mineral matter than that from the other formations. All the waters analyzed in the above table are carbonate waters with the exception of No. 5 from the Galena formation at Fennimore. The water from the Galena-Platteville limestone is very generally much higher in sulphate than the water from the underlying sandstone formations. Calcium and magnesium are the predominent basic constituents.

The water from the city well at Platteville, analyses No. 14, contains 2.80 pounds of incrusting solids in 1,000 gallons, and that from the city spring at Lancaster No. 2 contains 2.38 pounds in 1,000 gallons.

Mineral analyses of water in Grant County.

(Analyses in parts per million.)

<table>
<tr><th rowspan="2"></th><th colspan="3">Spring.</th><th>Alluvial sand.</th></tr>
<tr><th>1.</th><th>2.</th><th>3.</th><th>4.</th></tr>
<tr><td>Depth of well..................feet..</td><td>............</td><td>............</td><td>............</td><td>21</td></tr>
<tr><td>Silica (SiO_2)..............................</td><td>16.5</td><td>12.5</td><td>11.5</td><td rowspan="3">4.7</td></tr>
<tr><td>Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)</td><td>11.5</td><td>1.0</td><td>............</td></tr>
<tr><td>Aluminum oxide (Al_2O_3)...................</td><td>............</td><td>............</td><td>.6</td></tr>
<tr><td>Iron (Fe)....................................</td><td>............</td><td>............</td><td>Trace......</td><td>............</td></tr>
<tr><td>Calcium (Ca)..............................</td><td>28.7</td><td>69.5</td><td>67.7</td><td>46.5</td></tr>
<tr><td>Magnesium (Mg)..........................</td><td>6.9</td><td>26.1</td><td>23.9</td><td>24.9</td></tr>
<tr><td>Sodium (Na)...............................</td><td rowspan="2">1.6</td><td rowspan="2">1.3</td><td>14.8</td><td rowspan="2">10.2</td></tr>
<tr><td>Potassium (K)............................</td><td>2.9</td></tr>
<tr><td>Carbonate radicle (CO_3)...................</td><td>47.7</td><td>156.9</td><td>161.</td><td>135.9</td></tr>
<tr><td>Sulphate radicle (SO_4)....................</td><td>19.7</td><td>............</td><td>13.3</td><td>10.9</td></tr>
<tr><td>Chlorine (Cl)..............................</td><td>2.5</td><td>2.0</td><td>14.9</td><td>1.7</td></tr>
<tr><td>Organic matter...........................</td><td>31.2</td><td>............</td><td>............</td><td>............</td></tr>
<tr><td>Total dissolved solids......................</td><td>135.</td><td>269.</td><td>311.</td><td>235.</td></tr>
</table>

<table>
<tr><th rowspan="2"></th><th colspan="5">Galena-Platteville dolomite.</th></tr>
<tr><th>5.</th><th>6.</th><th>7.</th><th>8.</th><th>9.</th></tr>
<tr><td>Depth of well....................feet..</td><td>101</td><td>40</td><td>40</td><td>135</td><td>190</td></tr>
<tr><td>Silica (SiO_2)..............................</td><td>26.0</td><td>..........</td><td rowspan="2">5.6</td><td>8.4</td><td>3.6</td></tr>
<tr><td>Aluminum and iron oxides (Al_2O_3+ Fe_2O_3)..............................</td><td>24.5</td><td>1.0</td><td>............</td><td>3.1</td></tr>
<tr><td>Calcium (Ca)..............................</td><td>96.1</td><td>87.9</td><td>67.4</td><td>72.0</td><td>53.7</td></tr>
<tr><td>Magnesium (Mg)..........................</td><td>52.8</td><td>47.7</td><td>41.3</td><td>39.3</td><td>39.</td></tr>
<tr><td>Sodium (Na)...............................</td><td rowspan="2">14.8</td><td rowspan="2">8.6</td><td rowspan="2">9.2</td><td>8.0</td><td rowspan="2">17.2</td></tr>
<tr><td>Potassium (K)............................</td><td>.........</td></tr>
<tr><td>Carbonate radicle (CO_3)...................</td><td>156.5</td><td>207.8</td><td>203.4</td><td>153.6</td><td>184.5</td></tr>
<tr><td>Sulphate radicle (SO_4)....................</td><td>188.7</td><td>67.6</td><td>12.7</td><td>83.3</td><td>13.6</td></tr>
<tr><td>Chlorine (Cl)..............................</td><td>22.8</td><td>12.7</td><td>4.7</td><td>9.0</td><td>7.0</td></tr>
<tr><td>Total dissolved solids....................</td><td>582.</td><td>433.</td><td>344.</td><td>374.</td><td>322.</td></tr>
</table>

1. Spring of C. & N. W. Ry. Co. near Werley. Analyst, G. M. Davidson, Aug. 24, 1911.
2. Spring supplying city water works, Lancaster. Analyst, G. M. Davidson, Jan. 22, 1909.
3. Klondyke Spring at Lancaster. Analyst, A. S. Mitchell.
4. Well of C. M. & St. P. Ry. Co., Blue River. Analyst, Chemist C. M. & St. P. Ry. Co., Dec. 29, 1891.
5. Well of C. & N. W. R. Co., stock yards, Fennimore. Analyst, G. M. Davidson, Aug. 24, 1911.
6. Well of C. M. & St. P. Ry. Co., Platteville. Analyst, Chemist C. M. & St. P. Ry. Co., May 12, 1899.
7. Well of C. M. & St. P. Ry. Co., Platteville. Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 28, 1891.
8. Well of city water works, Montfort. Analyst, G. M. Davidson, Oct. 22, 1901.
9. Village well, Hazel Green. Analyst Dearborn Drug & Chem. Co., April 29, 1905.

Mineral analyses of water in Grant County—Continued.

(Analyses in parts per million.)

	Upper Cambrian (Potsdam) sandstone.						
	10.	11.	12.	13.	14.	15.	16.
Depth of well ....feet..	300	300	1,102	775	1,740	1,740	1,000
Silica (SiO_2)...............	1.3	....	27.0	2.1	9.9		1.8
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$).....	....	1.5	....	2.7	.8	.8	1.2
Calcium (Ca)...............	45.7	61.3	74.9	51.2	70.0	63.3	66.6
Magnesium (Mg)............	36.0	34.9	33.0	41.0	39.9	37.0	35.3
Sodium and potassium (Na+K).................	11.3	26.6	....	1.4	1.7	4.1	5.6
Carbonate radicle (CO_3)....	157.6	168.7	159.8	164.5	182.4	186.5	185.5
Sulphate radicle (SO_4)......	1.6	29.9	55.0	22.0	33.5	4.3	7.0
Chlorine (Cl)................	16.1	41.0	....	2.1	2.7	3.2	5.3
Total dissolved solids.......	270.	364.	349.	287.	341.	299.	308.

10. Well of C. M. & St. P. Ry. Co., Boscobel. Analyst, G. N. Prentiss, May 27, 1899.
11. Well of C. M. & St. P. Ry. Co., Boscobel. Analyst, Chemist C. M. & St. P. Ry. Co., Mar. 28, 1890.
12. Well of City Water Supply, Cassville. Analyst, Wahl & Henius.
13. Well of city water supply, Fennimore. Analyst, G. M. Davidson, Nov. 1, 1904.
14. Well of city water supply, Platteville. Analyst, G. M. Davidson, Jan. 22, 1909.
15. Well of city water supply, Platteville. Analyst, G. N. Prentiss, May 12, 1899.
16. Well of city water supply, Platteville. Analyst, Dearborn Drug & Chem. Co., Dec. 15, 1911.

GREEN COUNTY

Green County, located on the southern boundary of the state, has an area of 576 square miles, and a population of 21,641. About 94.4 per cent of the county is in farms, of which 62.6 per cent is under cultivation.

SURFACE FEATURES

The surface of Green County is characterized by undulating uplands in the western part and the broad flat-bottomed valley of the Sugar river in the eastern part. Below Albany the valley bottom of the Sugar river has a general width of 3 or 4 miles, while north of Albany the valleys of the various branches of the Sugar are generally one or two miles wide. The highest elevations in the county, along the divide, between the Pecatonica and Sugar rivers, are a little over 1,200 feet above sea level, while elevations in the northeastern part are about 1,100 feet, and in the southeastern part rarely exceed 1,000 feet. The elevation of the valley bottom of the Sugar river at Brodhead is about 780 feet,

and at Belleville, about 880 feet. The elevation of the Pecatonica valley at Martintown is about 780 feet. The difference in the altitude of valley bottom and adjacent upland ridges is therefore generally only a little over 200 or 300 feet.

GEOLOGICAL FORMATIONS

The geological formations, exposed within the county, are the Lower Magnesian limestone, the St. Peter sandstone, and the Galena-Platteville (Trenton) limestone. The Galena forms the main upland areas, and the St. Peter and Lower Magnesian, the valley bottoms. Glacial drift in relatively thin deposits is scattered over most of the county, and the valleys are filled with alluvium to a variable depth. The geological structure is illustrated in Fig. 38.

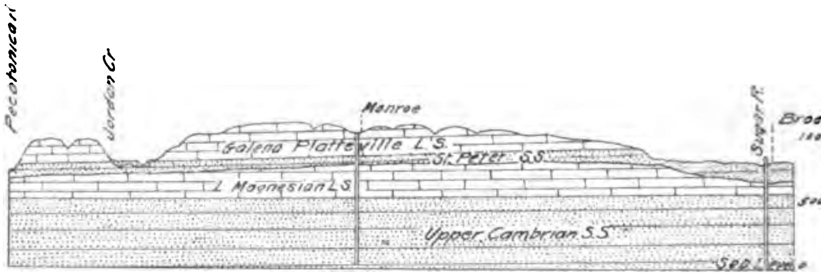

Fig. 38.—Geologic section, east-west, across Green County.

The thickness of the glacial deposits over the uplands is not important. While the known thickness of the river deposits in the valleys is only 140 feet at Brodhead, the maximum depth of the filled valleys very probably reaches 300 or 350 feet. The thickness of the rock formations appearing at the surface, is also quite variable on account of the extensive erosion of the strata. The approximate range in thickness of the formations may be summarized as folows:

Approximate range in thickness of formations in Green County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena-Platteville (Trenton) limestone	0 to 200
St. Peter and Lower Magnesian formation	50 to 200
Upper Cambrian (Potsdam) sandstone	700 to 900
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The chief water-bearing horizons are the Galena-Platteville (Trenton) limestone and the St. Peter sandstone. The Lower Magnesian which is mainly dolomite, but which also contains much sandstone, is drawn upon in the valleys. The deepest wells penetrate to the underlying Upper Cambrian (Potsdam) sandstone.

The wells in the valleys, in sand and gravel, range from 10 to 30 feet. The deepest wells on the upland range from 100 to 300 feet deep. The water level as a rule is less than 100 feet below the surface over the broad upland areas, the water usually being obtained either from the Galena-Platteville limestone or the underlying St. Peter sandstone.

FLOWING WELLS

Flowing wells in Green county are known to occur only in the vicinity of Brodhead, on low ground along the Sugar river. The source of the best flows at Brodhead appear to be in the upper strata of the Upper Cambrian (Potsdam) sandstone, at depth of about 300 feet. The normal head of the flowing wells appears to be at an altitude of 805 to 812 feet, from 5 to 15 feet above the surface. Flows should be obtainable on low ground along the Sugar river, farther up the valley.

WATER SUPPLIES FOR CITIES AND VILLAGES

Monroe.—The population of Monroe is 4,410. The city has a water supply system, the water being obtained from three 8 to 12-inch wells, 50, 880 and 997 feet deep. Elevation of the well curb is 1,012 feet, the water standing 40 feet below the surface. The water is from the St. Peter and Potsdam sandstone formations. The pumpage capacity is said to be 300,000 gallons per day, and the average daily pumpage is 272,000 gallons. The sewage is disposed of by the use of a septic tank and filter system. About 50 per cent of the houses have water and sewage connections. Common wells in Monroe vary in depth from 30 to 100 feet in drift and rock. The Electric Light Company's well, 700 feet deep, elevation of curb 1,047 feet, is now abandoned.

The deep well of the Borden Condensed Milk Co., elevation of curb about 1,004 feet, drilled in 1914, 16-in. hole 150 feet and 8-in. below has the following log, as interpreted by F. T. Thwaites from samples taken every 25 feet:

Log of Well of Borden Condensed Milk Co., Monroe.

Formation.	Thickness.
	Feet.
Surface clay	17
Galena-Platteville:	
Gray dolomite	108
St. Peter:	
Gray to brown-yellow sandstone, red shale at bottom	175
Lower Magnesian (Oneota):	
Gray dolomite with chert	75
Potsdam:	
Fine yellowish calcareous sandstone (Madison)	75
Dolomite and brownish shale (Mendota)	75
Calcareous and glauconitic sandstone (Franconia)	125
Gray and yellowish sandstone (Dresbach)	100
Brown shale and fine whitish sandstone (Eau Claire)	200
Coarse and fine sandstone and shale (Mt. Simon)	128
Total depth	1,113

Brodhead.—The population of Brodhead is 1,517. The city water supply is obtained from two 6-inch artesian wells 908 feet and 1,002 feet deep. The elevation of the curb is 798 feet. These wells are flowing, with heads of 5 and 14 feet above the surface. Capacity of wells reported to be 332,000 gallons per day. About 90 per cent of the people use the city water. No sewage system is installed.

The best flow in the city well No. 1 was secured at a depth of 300 feet after the well was cased to shut off the leakage in the crevices above. The same bed in the new well, No. 2, about one block west of No. 1, lies from 3 to 6 feet deeper than in the latter.

The strata penetrated at well No. 1 data furnished by Wm. Roantree is as follows:

Section of Brodhead city well No 1.

Formation.	Thickness.
Drift and alluvial formation.	Feet.
Sandy loam	2
Yellow sand	50
Yellow sand and gravel	48
Clay and sand	12
Clay and sand	18
Coarse sand	8
Lower Magnesian limestone formation.	
Broken stone	4
Calcareous shale	3
Sand and limestone	47
Limestone	33
Red marl	65
Drab shale	10
Upper Cambrian (Potsdam) sandstone formation	
White sandstone	52
Coarse white sandstone (first flow)	73
Blue calcareous shale	43
Blue slaty rock	40
Blue shale and sandstone	222
White sandstone	53
White sandstone	47
White sandstone	30
Coarse white sandstone	11
Coarse white sandstone	22
Sandstone, (no samples)	109
Total depth	1,002

F. M. Gray of Milwaukee who drilled the well says that the well ended in granite at a depth of 1,030, but the city authorities at Brodhead state that the well is only drilled 1,002 feet in depth. The well of the Artesian Well Co., elevation 802 feet, 500 feet deep, flows 4 feet above surface and the well of the Cemetery association, elevation 798 feet, depth 382 feet, flows 14 feet above the surface

Albany.—Albany has a population of 669. The wells in Albany generally vary from 10 to 125 feet in depth in the rock formation. The well of Wm. Smiley, about two miles west of the village, in section 30, is 290 feet deep in rock.

New Glarus.—The population of this village is 708. The private wells in the village vary from 30 to 50 feet deep in rock. The village has a public water supply from an 8-inch well, 186 feet deep, having an average pumpage of 50,000 gallons. About 50 per cent of the houses connect with the water supply.

QUALITY OF THE WATER

The water of Green County, as indicated in the table of analyses, are all hard waters or very hard waters, and all are of moderate mineral content. Only the waters analyzed from Monroe and Juda should be classed as very hard waters. The water of Gomber's well at Brodhead, in St. Peter sandstone, analyses No. 9, is unusually low in mineral content for this locality.

The waters analyzed from Monroe are unlike the others in the high content of chlorine, and the analyses of the city water in addition shows a high content of nitrate. Both of these constituents very probably indicate a contaminated source of supply. In the case of analyses No. 4 the well is only 30 feet deep and in the city supply of analyses No. 12, made in 1907, the nitrates and chlorides are probably in the water obtained from the 50-foot well. The analyses No. 13 of the Monroe city supply, from the deep 1,000-foot well, made in 1899, indicates a pure supply, without nitrates and high chlorine.

Mineral analyses of water in Green County.

(Analyses in parts per million.)

	Spring.	Surface deposits.				
	1.	2.	3.	4.	5.	6.
Depth of well..................feet..	....	26	18	30	11	40
Silica (SiO_2)........................ Aluminium and iron oxides (Al_2O_3+ Fe_2O_3)................	8.0	5.8	11.1	6.8	4.1	5.8
Calcium (Ca)........................	115.7	50.9	77.2	98.9	57.5	53.0
Magnesium (Mg)......................	42.9	21.9	36.5	35.4	31.6	28.2
Sodium (Na)........................ Potassium (K)........................	23.4	8.9	21.7	25.7	7.6	9.1
Carbonate radicle (CO_3).............	254.7	82.5	206.2	229.9	168.5	149.3
Sulphate radicle (SO_4)...............	39.9	87.3	5.6	24.5	5.0	7.5
Chlorine (Cl)........................	3.5	6.3	4.5	28.7	3.4	8.5
Total dissolved solids................	488.	264.	363.	450.	278.	261.

	Galena and Platteville limestone.		St. Peter sandstone.	Upper Cambrian (Potsdam) sandstone.			
	7.	8.	9	10.	11.	12.	13.
Depth of well........ feet..	25	25	30	1,002	1,002	50-997	1,000
Silica (SiO_2)...........			11.8	8.9		1.8	
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)............	4.4	.7			7.0	5.2	.7
Aluminium oxide (Al_2O_3)..			2.2	3.9			
Iron (Fe).....................	....	....	1.2	1.2	....	....	....
Calcium (Ca)................	126.0	88.4	28.1	46.3	46.6	78.5	74.1
Magnesian (Mg).............	19.8	47.4	13.8	33.5	33.4	50.7	38.3
Sodium (Na)................ Potassium (K)................	29.6	25.0	3.2	2.8	3.7	25.2	10.7
Potassium (K)................			....	1.1	....	....	....
Carbonate radicle (CO_3)....	136.5	240.4	77.7	163.8	148.9	205.7	191.6
Nitrate radicle (NO_3)........	....	....	....	....	....	34.	....
Sulphate radicle (SO_4).....	17.0	22.6	1.9	11.6	10.6	33.3	22.5
Chlorine (Cl)................	33.7	32.2	3.3	3.8	1.4	38.8	16.3
Organic matter	....	....	3.0	....	....	....	....
Total solids	367.	457.	143.	277.	252.	473.	354

1. Luxinger's Spring, Monroe. Analyst, Chemist C. M. & St. P. Ry. Co., May 29, 1891.
2. Well of C. M. & St. P. Ry. Co., Brodhead. Analyst, Chemist C. M. & St. P. Ry. Co., May 27, 1891.
3. Well of C. M. & St. P. Ry. Co., Juda. Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 5th, 1891.
4. Well of C. M. & St. P. Ry. Co., Monroe. Analyst, Chemist C. M. & St. P. Ry. Co., May 29, 1891.
5. Well of C. M. & St. P. Ry. Co., New Glarus. Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 28, 1891.
6. Well of C. M. & St. P. Ry. Co., Browntown. Analyst, Chemist C. M. & St. P. Ry. Co., May 25, 1891.
7. Well of C. M. & St. P. Ry. Co., Monroe. Analyst, Chemist C. M. & St. P. Ry. Co., May 29, 1891.
8. Well of C. M. & St. P. Ry. Co., Monroe. Analyst, Chemist C. M. & St. P. Ry. Co., April 27, 1899.
9. Gomber's well at Broadhead. Analyst, G. Bode, Vol. 2, Geol. of Wis., p. 660, 1877.
10. Well of city water works, Broadhead. Analyst, W. W. Daniells.
11. Well of city water works, Broadhead. Analyst, Chemist C. M. & St. P. Ry. Co., May 27, 1891.
12. Wells of city water supply, Monroe. Analyst, Dearborn Drug & Chem. Co., May 23, 1907.
13. Well of city water works, Monroe. Analyst, Chemist C. M. & St. P. Ry., April 29, 1899.

GREEN LAKE COUNTY

Green Lake County, located in the south central part of the state, has an area of 364 square miles, and a population of 15,491. About 90.3 per cent of the county is in farms, of which 62.6 per cent is under cultivation.

SURFACE FEATURES

The surface of Green Lake county varies from quite level and gently undulating in the western and northwestern part to somewhat more undulating and hilly in the southeastern part. The broad, low valley of the Fox river extends through the northwestern part. In the eastern and southeastern parts are upland ridges and tablelands, fluted by trough-like valleys extending in an east-northeast direction.

The general altitude of the valley bottom of the Fox river is between 750 and 780 feet, the river level at Berlin being 750, and at Lake Puckaway, 760 feet. Much of the valley bottom is only from 10 to 20 feet above the river level. The upland ridges in the eastern part of the county reach altitudes of 1,050 to 1,150 feet. Green Lake lies 25 to 35 feet higher than Lake Puckaway and has a depth of 287 feet. The upland ridges in the eastern part, near Green Lake, rise from 100 to 200 feet above the level of the lake and have broad, gently rolling tops occupied by farms.

GEOLOGICAL FORMATIONS

The principal geological formations are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, and the surface formations of alluvium and glacial drift. In the southeastern part of the county the St. Peter sandstone and the Galena-Platteville (Trenton) limestone are present. At Berlin, and in the northeastern part of the county, are outcrops of the Pre-Cambrian granite. The geological structure is illustrated in Fig. 39.

The thickness of the surface formations of river and lake deposit, and of glacial drift, is quite variable in the county. The pre-glacial channel of the Fox river has been filled to a depth of over 300 feet with gravel, sand and clay, as shown by well records near Berlin. Outside the old valley, however, the surface formations are usually less than 100 feet thick. The thickness of the rock formation of sandstone and limestone is also quite variable on account of the difference in amount

of erosion of these formations. The Lower Magnesian and the Galena-Platteville (Trenton) limestone formations occur only in the higher lands of the southeastern part of the county, being wholly removed by

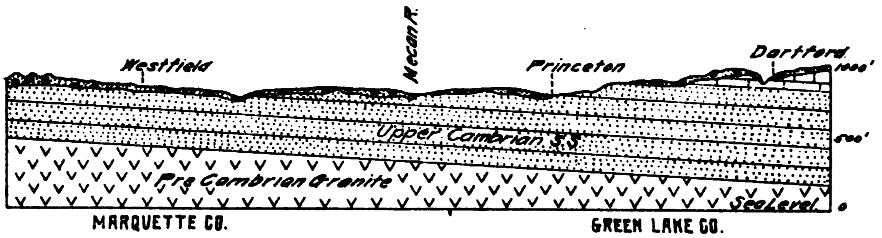

Fig. 39.—Geologic section, east-west, across northern Marquette and Green Lake counties.

erosion from the area adjacent to and west of the Fox river. The usual range in thickness of the formations in the county may be summarized as follows:

Approximate range in thickness of formations in Green Lake County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena-Platteville (Trenton) limestone	0 to 200
St. Peter and Lower Magnesian formations	0 to 250
Upper Cambrian (Potsdam) sandstone	0 to 750
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the Upper Cambrian (Potsdam) sandstone and the surface formations of alluvial sand, clay, and glacial drift. Most of the wells of the northwestern part of the county are shallow, on account of the generally level character of the land, the wells being generally from 15 to 20 feet deep. On the uplands of the eastern part of the county wells are generally from 50 to 150 feet deep.

FLOWING WELLS

Flowing wells occur throughout the county along the Fox river. The water is obtained from two sources—the surface formation and the underlying Potsdam sandstone. The head is generally from 10 to 20 feet above the level of the Fox river, rising slightly to higher altitudes

as the distance from the river is increased. (See page 91). The following wells are more fully described under water supplies for Berlin and Princeton.

WATER SUPPLIES FOR CITIES AND VILLAGES

Berlin.—This city, population 4,636, located on the Fox river, has a water supply and sewage system. The water supply is obtained from two 8-inch artesian wells 430 and 450 feet deep and 100 feet apart. The sewage is emptied without purification into the Fox river. About 50 per cent of the houses are connected with the water supply and sewage systems.

The two city wells flow 150 gallons per minute at the surface under a 3-foot head, and about 700 gallons per minute 20 feet below the surface of the ground. The water is pumped into a 100,000 gallon reservoir. The average pumpage is 171,000 gallons per day.

The water is obtained from two sources, the upper source is a gravel seam under 48 feet of clay, the lower is the Potsdam sandstone. About one-fourth of the water pumped comes from the gravel seam.

The city wells are located on low ground near the river, half a mile southwest of the Berlin rhyolite outcrop which rises about 200 feet higher than the surface at the well. No crystalline rock was encountered in either well. A slight variation in the amount of water has been noticed from one year to another. This variation is due chiefly to the supply from the gravel seam which is affected materially by the amount of rainfall.

A number of wells along the Fox river, varying in depth from 60 to 100 feet, draw their supply from the gravel bed above the sandstone. Two of these wells are used by the Sears Tannery Company, and are about 100 feet deep. At present nearly all of these wells have ceased flowing, the waterworks wells having reduced the heads of all the wells in the vicinity of the plant. One of the shallowest flowing wells drilled is only 25 feet deep, and flowed 12 feet above the surface, filling a 2-inch pipe. The glacial and associated deposit in this vicinity varies from 50 to more than 300 feet in thickness. Most of the flowing wells are between 80 and 150 feet in depth. In this connection see description of the flowing wells in Fox River valley pp. 90–93.

The following log of a well, in Sec. 10, the southern part of Berlin, shows the character and thickness of the surface formation in the valleys of this locality:

Drillers Log of well drilled by A. R. Heald in S. 10., T. 17. R. 13, in 1897.

Formation.	Thickness.
	Feet.
Sand and clay	20
Clay	45
Sand	10
Clay	135
Gravel and cement clay	20
Clay	40
Gravel and cement clay	54
Potsdam, red sandstone	42
Total depth	366

Princeton.—This village located on the Fox river has a population of 1,269. Artesian flows have been obtained near Princeton and farther up the Fox river, as described in Marquette county. Most of the wells in the village are from 24 to 90 feet deep in clay and sand.

Markesan.—Markesan, located on Grand river, has a population of 892. The water supply is obtained from private wells, which are generally from 35 to 65 feet deep in sand and gravel. The deepest wells reach into the Lower Magnesian limestone.

Green Lake.—This village, located on Green Lake, has a population of about 500. The private wells are of variable depth from 20 to 100 feet in drift and rock.

QUALITY OF THE WATER

The waters of Green Lake county, as shown in the table of analyses, are hard waters of moderate mineral content. The water of the Grove House spring at Green Lake is somewhat unusual and contains a relatively high content of magnesium sulphate, epsom salt, and is utilized for medicinal purposes. The water of Green Lake shows the same character as the water of some other lakes in Wisconsin, in containing a smaller amount of calcium than of magnesium, a condition undoubtedly brought about within the lake itself through the abstraction of calcium from the water by chara and other organisms.

The water from the Fox river at Princeton, No. 1, contains 2.28 pounds of incrusting solids in 1,000 gallons, and that from the well at Princeton, No. 7, contains 2.53 pounds in 1,000 gallons.

Mineral analyses of water in Green Lake County.

(Analyses in parts per million.)

	River.	Lake.	Spring.	Surface deposits.			Upper Cambrian (Potsdam) sandstone.
	1	2	3	4	5	6	7
Depth of well.............feet	....	....	....	10.	16.	109.	300.
Silica (SiO_2)	23.7	9.4	14.	6.1	2.2	35.5	24.0
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)	18.6	2.	....	....	....	17.8	12.8
Calcium (Ca)	43.1	21.5	59.5	70.9	63.1	59.5	59.1
Magnesium (Mg)	28.2	25.7	62.4	38.4	33.0	24.2	32.5
Sodium (Na)	3.6	3.4	1.3	10.9	14.3	7.2	1.8
Potassium (K)	....	3.	....	....	....	....	....
Carbonate radicle (CO_3)	118.9	87.	89.2	197.6	183.7	136.3	158.9
Sulphate radicle (SO_4)	36.3	16.7	246.5	18.5	12.8	26.9	18.0
Chlorine (Cl)	5.4	5.8	2.	7.5	3.9	3.2	0.0
Organic matter	1.5	....	....	....	....	....	....
Total dissolved solids	278.	174.	475.	350.	313.	311.	308.

1. Fox River, Princeton. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Feb., 1901.
2. Green Lake. Analyst, E. B. Hall and C. Juday, Wis. Geol. Hist. Survey. Bull. 22, p. 170. Sept. 14, 1907.
3. Spring Grove Epsom Spring, Green Lake. Analyst, A. F. Gilman.
4. Railroad well, Berlin. Analyst, Chemist C. M. & St. P. Ry. Co., Sept. 9, 1889.
5. Railroad well, Markesan. Analyst, Chemist C. M. & St. P. Ry. Co., Sept. 9, 1889.
6. Well of American Hotel, Princeton. Analyst, G. M. Davidson, Jan., 1901.
7. Well of C. & N. W. Ry. Co., Princeton. Analyst, G. M. Davidson, May 21, 1901.

Iowa County

Iowa county, located in the southwestern part of the state, has an area of 763 square miles, and a population of 22,497. About 92.5 per cent of the county is in farms, of which 63.4 per cent is under cultivation.

SURFACE FEATURES

The surface of Iowa county consists of deeply dissected uplands, whose nearly even summits reach an approximately common elevation. The valleys are quite generally V-shaped, or narrow flat-bottomed. The relatively high divide, separating the waters flowing north to the Wisconism river from those flowing south through the Pecatonica river to the Rock, extends east and west across the central part of the county. The highest elevations upon the divide generally rangs between 1,200

and 1,300 feet. The summit of Blue Mounds, however, reaches an altitude of approximately 1,720 feet. The lowest elevation along the Wisconsin river, along the northern border of the county, is about 700 feet. The lowest elevation along the flat-bottomed valley of the Pecatonica in the southern part is about 900 feet. The maximum difference in elevation between valley bottom and main uplands is 500 to 600 feet in the northern part of the county, and about 400 feet in the southern part.

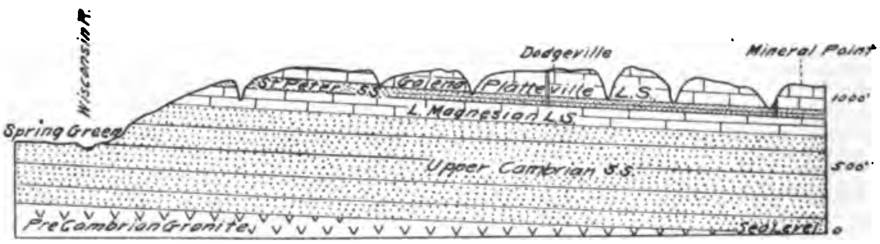

Fig. 40.—Geologic section, north-south, across central Iowa County.

GEOLOGICAL FORMATIONS

The geological formations of this county are like those of Grant county, and consist, from the base upwards, of the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, the St. Peter sandstone, and the Galena-Platteville limestone. The Potsdam occurs only in the valley of the Wisconsin river and adjacent tributaries. The Galena-Platteville limestone forms the main uplands of the southern part of the county. In the Blue Mounds, located on the boundary of Iowa and Dane counties, are the Maquoketa (Cincinnati) shale and the overlying Niagara limestone. A thin deposit of loess is common over the upland slopes. The valleys are filled to a variable depth with alluvial sand. The general geological structure is illustrated in Fig. 40.

The surface formation is mainly confined to the lower slopes and in the bottoms of the valleys, where a maximum thickness of 200 to 300 feet of river deposit of sand and silt is present. The thickness of the rock formations is variable on account of the extensive erosion of the strata. It is only where the formations are protected by the overlying formations that the complete sections are preserved. The Maquoketa shale occurs only in the Blue Mounds and in a small area a few miles northeast of Mineral Point. The Niagara limestone formation occurs only on the summit of the Blue Mounds. The complete thickness of the Galena-Platteville is usually between 250 and 300 feet, the Platteville beds being 50 to 60, and the Galena, 220 to 250 feet thick. The

usual thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Iowa County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone (only on Blue Mounds)	0 to 200
Cincinnati shale (Maquoketa)	0 to 200
Galena-Platteville (Trenton) limestone	0 to 300
St. Peter and Lower Magnesian	0 to 250
Upper Cambrian (Potsdam) sandstone	600 to 900
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

All of the geological formations from the Upper Cambrian (Potsdam) sandstone up to the Galena limestone are drawn upon for water supplies in various parts of the county. Over most of the uplands in the central and southern part of the county abundant supplies are obtained from the Galena-Platteville limestone. The relatively impervious strata at the base of the Galena limestone and at the base of the Platteville limestone control the underground circulation in these formations. In the valleys in the southern part shallow wells 10 to 40 feet deep generally find abundant water either in alluvial sands or in St. Peter sandstone. In the northern part of the county the St. Peter sandstone lies upon the upland ridges and where of sufficient thickness furnishes a good supply. Many of the wells in the northern part, however, are in the Lower Magnesian limestone and range in depth between 20 and 200 feet. Adjacent to the Wisconsin river the wells are generally in the Upper Cambrian (Potsdam) sandstone. In the valley plain along the Wisconsin, water is generally obtained at depth of 10 to 30 feet in the alluvial sand.

SPRINGS

No flowing wells are known to occur in the county, but numerous springs occur, most of which are seepage springs having their sources at the bases of the St. Peter sandstone, the Platteville limestone, and the Galena limestone. On the Blue Mounds numerous springs occur at the contact of the Cincinnati shale with the overlying limestone. The bed of blue shale overlying the St. Peter sandstone is a very common source of springs. Many of the springs are the heads of running

streams and furnish an excellent supply of cold water for domestic use. The springs often determine the location of the farm houses.

WATER SUPPLIES FOR CITIES AND VILLAGES

Mineral Point.—The population of Mineral Point is 2,925. The city water supply is obtained from an 8-inch well, 150 feet deep, from the St. Peter sandstone. The average pumpage is 30,000 gallons per day. The city has no sewage system. About 20 per cent of the houses connect with the water system. Private wells are generally from 60 to 150 feet deep.

The city well was started near the contact of the Platteville limestone and underlying St. Peter sandstone. The curb of the well is about 25 feet above the bottom of the valley.

The Mineral Point Zinc Co. has 6 wells, from 110 to 140 feet deep. Five of the wells are on the west side of the stream, and one on the east side, at the zinc oxide plant. The suction pipes in these wells extend down only 25 feet, but the water has never been lowered to this depth. During the running of the pumps about 20,000 gallons an hour were pumped from the wells. The water in the well on the east side is at the same height as that in the wells on the west side of the stream. After the pumps were stopped for 20 minutes the water stood 12 and 8 feet below the surface respectively, and at the end of forty minutes it had practically regained its normal head, being respectively 10 feet and 5½ feet below the surface.

At the Ice Company's plant the water is pumped from a well similar to the city well, and the water used in the manufacture of ice. The St. Peter sandstone, furnishes abundant quantities of water.

Dodgeville.—This city has a population of 1,791. The city water supply is obtained from three 8-inch wells, 130, 300 and 450 feet deep.

The 300 foot well passes through the Galena-Platteville limestone, and into the St. Peter sandstone about 100 feet. The average daily pumpage is reported to be only 50,000 gallons, there being less than 100 houses connected with the system. The city has no sewage system. Many private wells are reported 200 to 300 feet deep.

Highland.—Highland is located on the divide between streams flowing north to the Wisconsin river and those flowing south to the Platte and Pecatonica rivers. It has a population of 1,096. The highest part of the village is a little over 1,200 feet above sea level. The St. Peter sandstone lies at an altitude of 1,070 feet in the adjacent valley. An abundant supply of water can be obtained from wells reaching the St.

Peter sandstone at depths of 50 to 130 feet, depending on the altitude of the surface.

Linden. This village, population 580, has a public water supply obtained from a 10-inch well, 575 feet deep. The well probably reaches 150 to 200 feet into the Potsdam sandstone. No sewage system is installed. About 25 per cent of the houses are connected with the water system. Private wells generally vary from 80 to 100 feet deep.

Avoca. This village is located in the valley of the Wisconsin river. The population is 436. The water supply is obtained from private wells, generally quite shallow, from 10 to 30 feet deep, in sand and gravel. A public supply was recently installed, obtained from a well 50 feet deep.

QUALITY OF THE WATER

The composition of the water supplies of Iowa county is shown in the following table of mineral analyses. In general the water from the St. Peter sandstone, and that from the surface deposits, is hard water and much less mineralized than that obtained from the Trenton limestone, which is very hard water. The greater softness of the water in the St. Peter sandstone as compared with that in the Trenton limestone, seems to indicate that it is generally advisable to drill wells through the limestone and draw the supply from the underlying sandstone formation. The water in the Upper Cambrian (Potsdam) sandstone is also very likely to be appreciably softer than that in the Trenton.

All the waters analyzed are carbonate waters, though all those from the Galena-Platteville (Trenton) are relatively high in sulphates. The alkalies are subordinate to calcium and magnesium.

In this connection reference should be made to the analysis No. 5 of water from a 14-foot well near stockyards at Mineral Point. The water from this well showing high chlorine and other constituents is undoubtedly contaminated from surface sources, and does not represent a pure water of the locality.

The water from the railroad well at Montfort Jct., No. 12, from the St. Peter sandstone, contains 2.35 pounds of incrusting solids in 1,000 gallons, while that from the railroad well at Barneveld, No. 8, from the Galena-Platteville limestone, contains 3.84 pounds in 1,000 gallons. The softest water analyzed in the county is from the well in alluvial sand at Avoca, No. 3, which contains about 1.5 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Iowa County.

(Analyses in parts per million.)

	Creek.	Spring.	Surface deposits (alluvial).		
	1.	2.	3.	4.	5.
Depth of well.....feet..	....	....	25	18	14
Silica (SiO_2).....	undet.	13.0	1.3	2.0	undet.
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$).....		3.0	....	....	
Calcium (Ca).....	64.7	54.5	35.7	77.3	159.2
Magnesium (Mg).....	40.6	29.8	8.8	44.3	60.7
Sodium and potassium (Na+K).....	21.0	12.6	20.3	18.2	76.6
Carbonate radicle (CO_3).....	168.0	144.9	82.7	225.8	38.2
Sulphate radicle (SO_4).....	39.1	29.1	20.3	4.9	415.8
Chlorine (Cl).....	32.2	7.0	7.5	24.4	118.8
Nitrate radicle (NO_3).....	8.9	....	....	....	64.5
Total dissolved solids.....	376.	294.	177.	397.	934.

	Galena-Platteville (Trenton) limestone.				St. Peter sandstone.	
	6.	7.	8.	9.	10.	11.
Depth of well.....feet..	142	198	170	180	260	252
Silica (SiO_2).....	5.1	7.7	20.0	8.9	7.9	9.1
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$).....	9.0	8.0	3.6	2.0	7.9	1.0
Calcium (Ca).....	75.0	83.0	64.5	81.3	59.7	65.5
Magnesium (Mg).....	40.8	55.5	67.1	47.6	32.6	38.9
Sodium and potassium (Na+K).....	3.6	24.0	15.5	13.5	3.1	2.2
Carbonate radicle (CO_3).....	155.6	188.9	189.5	209.2	156.1	185.0
Sulphate radicle (SO_4).....	90.7	133.1	117.0	63.8	22.4	19.5
Chlorine (Cl).....	5.4	24.2	24.1	16.5	4.7	3.4
Organic matter.....	....	....	....	....	....	14.5
Total dissolved solids.....	385.	524.	501.	443.	294.	325.

1. Creek at Mineral Point. Analyst, G. N. Prentiss, July 10, 1912.
2. Spring at Cobb, depth 10 ft. in Trenton limestone. Analyst, G. M. Davidson, Jan. 29, 1909.
3. Well of C. M. & St. P. Ry. Co., Avoca. Analyst, Chemist C. M. & St. P. Ry. Co., July 23, 1891.
4. Well of C. M. & St. P. Ry. Co., at Mineral Point. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 3, 1891.
5. Well of C. M. & St. P. Ry. Co., Mineral Point. Analyst, G. N. Prentiss, May 8, 1912.
6. Well of C. & N. W. Ry. Co., Dodgeville. Analyst, G. M. Davidson, Feb. 2, 1909.
7. Well of C. & N. W. Ry. Co., Barneveld. Analyst, G. M. Davidson, Sept. 8, 1909.
8. Well of C. & N. W. Ry. Co., Barneveld. Analyst, G. M. Davidson, Jan. 29, 1909.
9. Well of C. & N. W. Ry. Co., Barneveld. Analyst, G. M Davidson, May 28, 1895.
10. Well of C. & N. W. Ry. Co., Rewey. Analyst, G. M. Davidson, Jan. 22, 1909.
11. Well of C. & N. W. Ry. Co., Rewey. Analyst, G. M. Davidson, Jan. 28, 1903.

***Mineral analyses of water in Iowa County*—Continued.**

(Analyses in parts per million.)

	St. Peter sandstone.						
	12.	13.	14.	15.	16.	17.	18.
Depth of well ....feet..	224	140	152	152	208	220	220
Silica (SiO_2)..................	19.4	1.2	....	....	....	....	....
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)............	6.3	....	undet.	undet.	undet.	undet.	undet.
Calcium (Ca)................	55.5	56.2	81.5	113.5	142.8	110.1	68.5
Magnesium (Mg)............	31.5	37.1	42.7	50.9	57.5	51.5	38.5
Sodium and potassium (Na+K)......................	12.0	4.5	10.8	30.3	42.0	40.8	5.3
Carbonate radicle (CO_3)....	150.4	176.3	178.1	200.2	200.1	184.8	166.4
Sulphate radicle (SO_4)......	9.0	6.1	69.0	125.2	172.6	116.0	38.0
Chlorine (Cl)................	1.7	2.4	23.8	67.1	119.9	73.8	11.1
Nitrate radicle (NO_3).......	....	....	....	....	....	50.5	7.7
Total dissolved solids.......	286.	284.	406.	587.	735.	628.	336.

12. Well of C. & N. W. Ry. Co. at Montfort Junction. Analyst, G. M. Davidson, Oct. 7, 1910
13. Well of Mineral Point Zinc Co., Mineral Point. Analyst, Chemist C. M. & St. P. Ry. Co., Dec. 19, 1894.
14. Well of C. M. & St. P. Ry. Co., Mineral Point. Analyst, G. N. Prentiss, April 22, 1913.
15. Well of C. M. & St. P. Ry. Co., Mineral Point. Analyst, G. N. Prentiss, April 14, 1913.
16. Two wells of C. M. & St. P. Ry. Co., Mineral Point. Analyst, G. N. Prentiss, April 8, 1912.
17. Well of C. M. & St. P. Ry. Co., Mineral Point. Analyst, G. N. Prentiss, May 8, 1912.
18. Well of C. M. & St. P. Ry. Co., Mineral Point. Analyst, G. N. Prentiss, July 10, 1912.

IRON COUNTY

Iron county, bordering on Lake Superior, has an area of 786 square miles and a population of 8,306. Only about 2.8 per cent of the county is in farms, of which 28 per cent is under cultivation. Hurley and Montreal are the largest towns.

SURFACE FEATURES

The surface of the county is generally undulating, the Penokee-Gogebic Range extending northeast through the north-central part. Altitudes range from 602 feet along Lake Superior to 1,600 and 1,800 feet on the Penokee range and farther south in the southern part of county. The southeastern part is dotted with many small lakes and numerous swampy tracts. The soil in the northern part is mainly clayey loam, and in the southern part mainly lighter sandy loams.

GEOLOGICAL FORMATIONS

The indurated rock formations from south to north are the Pre-Cambrian granitic and metamorphic formations, the Keweenawan trap and the Lake Superior sandstone. Over these indurated rocks are the surface deposits of glacial drift, red lacustrine clays and stratified sands.

The Keweenawan trap and Lake Superior sandstone lie in the northern part, north of the Penokee iron range, the sandstone being confined to a small area near the lake shore at Oronto Bay.

The vertical depth of the trap and the Pre Cambrian (Huronian) crystalline rocks is very considerable. The sandstone is also a very thick formation, with bedding dipping to 50° to 90° to the northwest. The thickness of the sandstone is estimated to be 12,000 to 14,000 feet. The thickness of the surface deposits is variable and ranges from nothing up to 300 or 400 feet. The maximum thickness of surface deposits probably occurs in the vicinity of Oronto Bay, and among the hills of terminal moraine in the central and southern part of the county. The approximate range in thickness of formations in Iron County may be summarized as follows:

Range in thickness of formations in Iron County.

Formation.	Thickness.
	Feet.
Surface formations	0— 400
Lake Superior sandstone	0—14,000
Keweenawan trap and Archean	....

PRINCIPAL WATER BEARING HORIZONS

The principal water bearing horizon is the surface formation of drift and stratified sand and gravel. Usually an abundant water supply can be obtained in this formation at depths of less than 50 feet. The Lake Superior sandstone is of uncertain character with respect to its water bearing capacity but usually a sufficient supply for farm purposes can be obtained from it.

The massive granite, quartzite, and trap rocks are generally low in water bearing capacity though small amounts can generally be obtained in these formations sufficient for farm supplies.

No artesian wells appear to be developed along the small portion of this county bordering on Lake Superior. It seems quite likely, however, that flowing wells in the surface deposits may be found in low places in the small valleys adjacent to the lake shore.

WATER SUPPLIES FOR CITIES AND VILLAGES

At Upson and Montreal, wells seldom are deeper than 25 feet, at which depth a sufficient supply of water is obtained from the sand and gravel underlying the drift clay. Numerous springs are found in this locality. A spring within the village of Upson could at a small expense be made to supply water sufficient for a town of 1,000 inhabitants.

At Hinkle and Kimball spring water is used entirely for the lumbering camps.

Hurley. Hurley, a city of about 2,000 inhabitants, has a public water supply, for fire protection mainly, obtained from Montreal River. An adequate pure water supply could readily be obtained for this place from underground water sources. A filter plant was recently installed to purify the river supply. (See p. 136).

Saxon. At Saxon, near the crest of the Keweenawan trap range, wells are from 20 to 40 feet in depth. They draw their supply mainly from gravel, between the layers of red clay and the underlying hard pan. Wells reaching to trap rock are of rare occurrence. Some water is also drawn from the sand overlying the red clay. Wells in drift are from 10 to 20 feet in depth, but are not very satisfactory from a sanitary point of view. The water stands about 10 feet below the surface. Numerous springs occur at various places in the swamp and marshes near the village. Drilled wells furnish a fair supply for all domestic purposes, but do not furnish a sufficient amount for railroad engines or other important economic uses. The underground water conditions at Saxon are much the same as at other localities along the ridge of trap rock.

The C. & N. W. Ry. Co. has drilled two wells near Saxon to supply their locomotives. The first well is cemented down for 43 feet, and draws its supply from 3 feet of gravel lying on the trap rock. It was drilled 43 feet further into the trap rock but secured no increase in flow. The water supply stands 6 to 10 feet above the surrounding swamp water, subject to seasonal variation. The well can be pumped dry in a few hours.

The second railway well is 500 feet north of the first. Two pumps, together lifting 15,000 gallons per hour, pumped this well dry in a few hours. Pumping from this well does not affect the water level in the first well.

The well of the John Schroeder Lumber Company at a camp in section 15, T. 47, R. 1 W., is 300 feet in depth, passing through clay and fine sand, until gravel was reached.

QUALITY OF THE WATER

The surface waters of Iron County are very soft or soft waters, as indicated by the analyses cited in the table. The waters analyzed from the springs, creeks and rivers show a very low content of mineral matter, about the same content of mineral matter as the water of Lake Superior.

The water from the well at De Fees mill at Saxon is hard water and contains 2.15 pounds of incrusting solids in 1,000 gallons. The city water supply of Hurley from the Montreal river, contains 0.60 pounds of incrusting solids in 1,000 gallons.

The high organic matter in the city water at Hurley, however, is a bad feature for both industrial and domestic use. The same water plant supplies the city of Ironwood, Mich. A good pure water supply could readily be obtained for both of these cities from ground water sources. A filter system was recently installed to remove the organic matter and other impurities in the river supply.

Mineral analyses of water in Iron County.

(Analyses in parts per million.)

	Creeks. River.			Springs.	Surface deposits.
	1.	2.	3.	4.	5.
Depth of well....feet	.....	.....	.....	.....	35
Silica (SiO_2)	11.8	8.2	9.2	10.5	18.8
Aluminum and iron oxides $Al_2O_3+Fe_2O_3$)	0.8	4.4	2.2	1.3	3.9
Calcium (Ca)	8.2	15.3	16.0	2.6	55.0
Magnesium (Mg)	4.8	4.3	6.3	trace	27.8
Sodium and potassium (Na+K)	2.2	2.7	1.8	1.8	1.2
Carbonate radicle (CO_3)	23.5	33.6	38.8	4.0	154.2
Sulphate radicle (SO_4)	3.5	2.0	2.7	2.6	2.0
Chlorine Cl	.....	.....	.....	.....	.....
Organic matter	36.0	12.5	54.4	9.7	19.8
Total dissolved solids	55.	70.	77.	23.	263.

1. Creek 4 miles northeast of Cedar. Analyst, G. M. Davidson, Dec., 1900.
2. Creek at Mercer. Analyst, G. M. Davidson, Sept. 23, 1909.
3. Montreal river, City Water Supply, Hurley. Analyst, G. M. Davidson, Aug., 1909.
4. Spring 1½ miles north of Cedar. Analyst, G. M. Davidson, Dec., 1900.
5. Well at De Fee's mill at Saxon. Analyst, G. M. Davidson, June 3, 1902.

JACKSON COUNTY

Jackson county, located in the west central part of the state, has an area of 978 square miles, and a population of 17,705. About 59.2 per cent of this county is in farms, of which 48.3 per cent is under cultivation, mainly in the western part of the county.

SURFACE FEATURES

The eastern part of the county is a broad, sandy alluvial plain, while the western part, west of Black river, is hilly, uneven land, characteristic of the sandstone formation.

The altitudes range from less than 800 feet along the valley of the

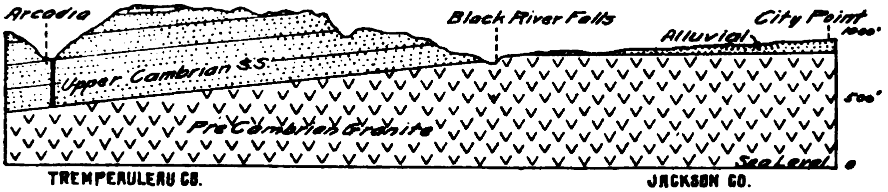

Fig. 41.—Geologic section, east-west, across central Trempealeau and Jackson counties.

Black river to 1,100 and 1,200 feet on the sandstone uplands. The broad sandy bottom plain of the eastern part of the county is mainly between 950 and 1,000 feet above sea level.

GEOLOGICAL FORMATIONS

The Pre-Cambrian crystalline formations of granite and gneiss occur along the bed of the Black river, above Black River Falls. Overlying the crystalline rocks over all other parts of the county is the Upper Cambrian (Potsdam) sandstone. East of the Black river is the broad plain of sandy alluvial formation, a relatively low tract, characterized by wet and marshy areas. A large amount of alluvial filling occupies the valley of the Black river below Black River Falls, and similar surface deposits occur in all other valleys of the county. The geological structure of Jackson and Trempealeau counties is illustrated in Fig. 41.

The surface formation probably attains a maximum thickness of over 200 feet in the deepest parts of the filled valleys. The thickness of the

Upper Cambrian (Potsdam) sandstone is variable on account of the extensive erosion of the strata. The approximate range in thickness of the geological formations may be summarized as follows:

The range in thickness of formations in Jackson county.

Formation.	Thickness.
	Feet.
Surface formation	0 to 200.
Upper Cambrian (Potsdam) sandstone	0 to 800.
The Pre-Cambrian granite	....

WATER SUPPLIES FOR CITIES AND VILLAGES

Black River Falls. This city, the county seat of Jackson county, has a population of 1,917. It is situated on the site of a large water power on the Black river. The bed rock, in the river rapids, is the granite formation, and overlying this are some ledges of sandstone and a thick deposit of loose sand and gravel of alluvial origin. The principal part of the city is located on a sandy alluvial terrace on the west side of the river. During the high water stage of September, 1911, the river broke through at the west end of the dam and destroyed a considerable part of the city located on the lowest terrace.

The city water supply is derived from springs located about 4 miles from the city and a well 10 feet deep located at the pumping station. The average daily pumpage is 100,000 gallons. Sixty per cent of the houses are reported to be connected with the water system. No sewage system is installed.

Merrillan. Merrillan, located on Halls Creek, has a population of 625. It is located upon a level area of sand and sandy loam soil. A public water supply is installed, the supply being obtained from four Cook points in a bed of sand, 17 to 30 feet from the surface. The average daily pumpage is 40,000 gallons. About 50 per cent of the houses are connected with the system. The private wells are shallow, from 10 to 20 feet deep.

Hixton. At Hixton the wells are in sand and sandstone to depths of 15 to 60 feet. In Irving the wells are from 25 to 50 feet in sand and sandstone rock. In Millston the wells are from 20 to 70 feet deep in the sand and sandstone formation. In Taylor wells are from 20 to 50 feet in sand and gravel.

Alma Center. Alma Center, population 417, has a public water supply obtained from a 6-inch well, 386 feet deep. The formation is 20 feet of surface sand, and 336 feet of the Upper Cambrian (Potsdam) sandstone. The water level stands near the surface, and the daily capacity of the supply is about 216,000 gallons. The average daily pumpage is 8,000 gallons. About 50 per cent of the houses are connected with the system.

QUALITY OF THE WATER

Judging from the character of the geological formation, the water is very likely to be soft in the alluvial sand, and hard water of moderate mineral content of from 100 to 300 parts per million in the sandstone formation. The water of the Black river is very probably soft water containing less than 100 parts per million of mineral matter. Analysis of the soft water characteristic of the alluvial sand formation is shown in No. 3 of the table of analyses.

Mineral analyses of water in Jackson County.

(Analyses in parts per million.)

	Creek.		Surface sand or sandstone.
	1.	2.	3.
Silica (SiO_2) Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	3.7	7.5	8.6
Calcium (Ca)	3.4	8.3	7.0
Magnesium (Mg)	0.7	4.1	3.5
Sodium and potassium (Na+K)	5.1	14.9	....
Carbonate radicle (CO_3)	10.4	38.7	16.8
Sulphate radicle (SO_4)	4.3	2.7	9.8
Chlorine (Cl)	0.5	1.6	1.6
Total dissolved solids	28.	78.	47.

1. Morrison Creek, at McKenna, an abandoned station on Goodyear Logging R. R., in Sect. 21 or 28, T. 21 N., R. 1 W. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 17, 1892.
2. Morrison Creek mill pond at McKenna. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 11, 1892.
3. Well near Sulsich & Co.'s office, at McKenna. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 15, 1892.

Jefferson County

Jefferson county, located in the southeastern part of the state, has an area of 548 square miles and a population of 34,306. About 95 per cent of the county is in farms, of which 64.9 per cent is under cultivation.

SURFACE FEATURES

The surface is largely a broad valley bottom plain with only a small proportion of upland area reaching 100 to 200 feet above the valley bottoms. The county is drained by Rock river and its tributaries mainly the Crawfish and the Bark rivers. Broad marshes are a characteristic feature of the eastern part of the county especially along the

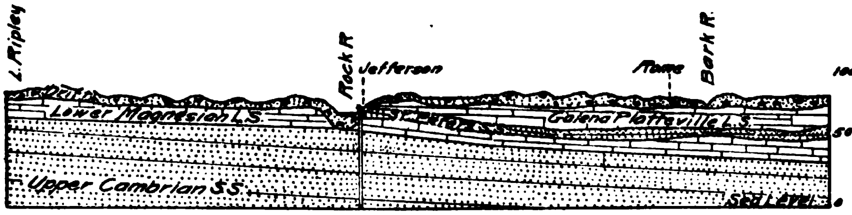

Fig. 42.—Geologic section, east-west, across central Jefferson County.

Bark and Scuppernong rivers. Elsewhere small marshes quite generally lie at the base of the oval ridges, "drumlins", which are common in Jefferson county.

The lowest part of the county, Lake Koshkonong, lies at an elevation of 779 feet above sea level. The general level of the land along Rock river is a little below 800 feet in the southwestern part of the county, and a little above 800 feet in the northern part, above Watertown. The bottoms of the tributary valleys of the Crawfish and Bark rivers are also only a little above 800 feet where they enter the county. Most of the elongated ridges reach an elevation of 900 feet to 950 feet, and only a very few exceed 1,000 feet. A belt of terminal moraine lies across the southeastern corner of the county, southeast of Palmyra.

GEOLOGICAL FORMATIONS

The geological formations are the Lower Magnesian limestone, the St. Peter sandstone and the Galena-Platteville (Trenton) limestone.

Glacial drift is fairly abundant over the whole of the county, and in the valleys there is a considerable amount of stratified gravel and sand. The Galena and Platteville (Trenton) limestone form a fairly continuous bed east of Rock river; west of the river are the Platteville the St. Peter and the Lower Magnesian formations. The geological structure is illustrated in Fig. 42.

The usual range in thickness of the geological formations in Jefferson county may be summarized as follows:

Probable range in thickness of the formations in Jefferson County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena and Platteville limestone	0 to 250
St. Peter and Lower Magnesian formation	200 to 250
Upper Cambrian (Potsdam) sandstone	600 to 800
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the St. Peter and the Upper Cambrian (Potsdam) sandstones, the glacial drift and the alluvial deposits. The Galena-Platteville (Trenton) limestone is an important source for wells in the eastern part of the county. Many shallow wells in the rural districts are from 20 to 100 feet deep in the glacial drift. Usually abundant water is obtained at shallow depth, less than 100 feet.

FLOWING WELLS

Flowing wells are common on low ground throughout Jefferson county. Flows are obtained from the surface deposits as well as from the underlying strata. Flowing wells occur along Rock river and tributaries at Jefferson, Ft. Atkinson, Watertown and Waterloo, as described under the water supplies of these cities. Some of the flows are obtained in the drift and in Galena-Platteville limestone, but the usual source is the underlying St. Peter and Upper Cambrian (Potsdam) sandstone formations, the head being generally from 5 to 20 feet above the level of the river adjacent.

Numerous flowing wells are found in the vicinity of Ft. Atkinson, ranging in depth from 200 to 500 feet. Besides the artesian wells from the St. Peter and Potsdam sandstone, artesian flows are obtained from glacial drift all along the lowlands bordering Rock river. The drift

in this locality, in many places, is over 200 feet deep. Most of the artesian flows are found in Secs. 1, 4, 3, 6, 9 and 12 of Koshkonong township. (See page 96).

There are many flowing wells in Palmyra township, along the Scuppernong river. Artesian flows are struck in the drift in Galena-Platteville (Trenton) limestone and in the St. Peter sandstone, the wells ranging in depths from 50 to 400 feet. The largest number of flows are obtained in Secs. 8, 14, 16, 19, 20, 21, 23, 28, 29, 30 and 31, T. 5 N., R. 16 E. (See also page 75.)

SPRINGS

Springs are a common source of water supply in Jefferson county, about the border of marshy tracts and along the streams. The large springs in the vicinity of Palmyra are especially well known. The springs at Palmyra issue from the drift along the base of the terminal moraine ridges, the Kettle Range, and have their ultimate source in the rainfall in the morainic hills.

WATER SUPPLIES FOR CITIES AND VILLAGES

Fort Atkinson. The population of Fort Atkinson is 3,877. The city water supply is mainly obtained from a flowing well 750 feet deep. The supply is connected by an intake from the Rock river at a depth of 5 feet used in case of emergency. The average daily pumpage is 262,000 gallons. About 65 per cent of the houses are connected with the system. The sewage, without treatment, empties into the Rock river. The city well is cased 250 to rock with 10-inch casing, and is 8 inches in diameter within the rock. The flow at the surface was 950 gallons per minute when first completed, and some flow would take place over the top of a 3-inch pipe, 28 feet above the surface. The well flows into a large covered reservoir, from which it is pumped into the mains.

Jefferson. The population is 2,582. The city water supply is obtained from a flowing well, 782 feet deep. The average daily pumpage is 110,000 gallons. About 65 per cent of the houses are connected with the water supply. The sewage, without purification, is emptied into the Rock river. Families living on the outskirts of the city have cess pools. The city well is 10 inches in diameter and is cased 185 feet to rock. The deepest well at Jefferson is the County Farm well 998 feet deep, 40 feet to rock and striking granite at 988 feet. The water in this well rises to 13 feet below the surface.

The section of the city well, elevation of curb 794, is as follows:

Log of Jefferson city well, altitude 794 ft.

Formation.	Thickness.
Pleistocene.	Feet.
Clay	160
Gravel	10
Fine sand	10
Coarse gravel	15
St. Peter, Lower Magnesian and Potsdam.	
Red sandstone	82
White sandstone	38
Shaly sandstone	5
Gray shale	10
Red sandstone	10
Red shale	9
Gray sandstone	3
Red sandstone	4
Gray sandstone	3
Red sandstone	4
Gray sandstone (Calcareous)	22
Red sandstone	74
Sandstone	100
Silicious rock	36
Red sandstone	2
Sandstone	180
Total depth	782

All the wells in the city failed to strike limestone in the Lower Magnesian horizon.

The section of the Jefferson County Farm well, elevation of curb 826, is as follows:

Log of County Farm well.

Formation.	Thickness.
	Feet.
Drift	40
Limestone (Trenton)	100
Sandstone (St. Peter, Lower Magnesian and Potsdam)	848
Granite (Pre Cambrian)	10
Total depth	998

Watertown. The population of this city, partly in Dodge but mainly in Jefferson county, is 8,829. The city has a water supply and sewage system. The average daily pumpage is 723,000 gallons. The sewage, without purification, is discharged into the Rock river, in the southern part of the city, which is considered objectionable. About 60 per cent of the houses are supplied with water and sewer connections.

The water supply is obtained from three 8-inch wells, No. 1, drilled in 1892, 600 feet deep, cased 300 feet, and No. 2 drilled in 1896, 1,145

feet, cased 250 feet, and No. 3, drilled in 1911, 745 feet deep. The elevation of the curb of the No. 2 drilled in 1896, is 809 feet, and the water flows 11 feet above the surface. The elevation of the curb of No. 1, the 600- foot well, drilled in 1892, is 823 ft. and the water rises to 4 feet below the surface. Records are at hand of 6 other wells in Watertown, ranging in depth from 168 to 385 feet, four of which are flowing wells from 4 to 14 feet above the surface, and in two the water rises within 3 feet of the surface. Many private wells vary in depth from 10 to 40 feet.

In the Watertown city wells the temperature of the water is 48° to 50° F., depending upon depth. At most of the wells the strata penetrated are much alike, the chief difference being in the thickness of the overlying drift. No Lower Magnesian limestone appears to be present; if there is any, it is very thin. Five feet of limestone is reported at the city well, between the St. Peter and Upper Cambrian (Potsdam), but whether this is one of the limestone beds of the Lower Magnesian limestone, or whether it belongs to the limestone beds of the upper part of the Upper Cambrian (Potsdam) is not known. The pre-Cambrian quartzite (or associated slate), like that outcropping at Waterloo, is reached in several places before penetrating the normal thickness of the sandstone.

Flows are struck at several horizons, the first one at the shale layer within the Galena-Platteville (Trenton) limestone. Water from this source has a very low head and flows only at the low places. An ex ample of this class is the well on the island in the Rock river, east of the city. The C. & N. W. Ry. well, depth 55 feet, flowing capacity 25,000 to 30,000 gallons in 10 hours, may, also belong to this class.

With the exception of the deepest city wells, most of the deeper flowing wells in the city get their supply from the St. Peter sandstone, which has a considerably higher head than the wells in the Galena-Platteville limestone. Over 50 wells have been sunk into the St. Peter sandstone and furnish flowing wells. Many of these have been neglected and at present do not flow. The city wells also affect the head of these wells, in part, by pumping and in part by allowing the water from the St. Peter horizon free flow outside of the inner casing at an altitude of about 820 feet, which is considerably lower than the mouth of many of the uptown wells. This, with the abandoned wells, greatly reduces the head of the St. Peter horizon.

The St. Peter sandstone outcrops a few miles to the west at approximately the same elevation as in the city and it is very probable that the feeding area lies toward the northwest, but there can be no doubt that in part this head is maintained by the pressure of water in the

underlying Potsdam sandstone horizon, which in places at least is in direct contact with the St. Peter sandstone and has the same head in the wells.

Here is another case indicating how friction in underground waters favors artesian flows. If these old wells could be plugged so as to prevent the escape of the waters into the drift at lower depths than the curbs of the flowing wells, pressure at the various flowing wells could be considerably increased.

The following is the log of the 1,145 foot city well, samples of which were sent by the Mayor of Watertown to Professor J. M. Clements at the University of Wisconsin, in 1896:

Log of Watertown city well No. 2.

Formation.	Depth.	Thickness.
	Feet.	Feet.
Pleistocene:		
Drift	0— 60	60
Galena-Platteville (Trenton):		
Limestone	60—110	50
St. Peter.		
Sandstone	110—320	210
Lower Magnesian (?).		
Limestone	320—325	5
Upper Cambrian (Potsdam).		
White sandstone	325—455	130
Brown sandstone	455—495	40
White sandstone	495—545	50
Red shale	545—550	5
Pink sandstone	550—590	40
Pink limestone	590—630	40
Red shale	630—635	5
Pink sandstone	635—712	77
Shale and streaks of red sandstone	712—760	48
Sandstone	760—770	10
Shale and sandstone	770—1,000	230
Hard silicious shale	1,000—1,085	85
Archean.		
Granite	1,085—1,145	60
Total depth		1,145

The log of the city well No. 3, based on examination of samples by F. T. Thwaites, in 1911, is as follows:

Log of Watertown city well No. 3.

Formation.	Depth.	Thickness.
Pleistocene.	Feet.	Feet.
No sample	0-15	15
Glacial till	15-30	15
Coarse, reddish brown sand	30-40	10
Very calcareous reddish brown sand	40-59	19
Trenton limestone.		
Hard dolomitic limestone top half light brownish color, lower half gray	59-100	41
St. Peters sandstone.		
Light gray to pinkish fine grained, slightly calcareous sandstone	100-180	80
Gray sandstone mixed with white chert and bluish calcareous shale	180-215	35
Lower Magnesian limestone.		
Gray, sandy dolomitic limestone, showing some chert at the top and a little iron oxide and blue shale	215-228	13
Potsdam sandstone.		
Fine to medium grained grayish, slightly calcareous quartz sandstone with a few dark iron grains and sometimes a little sandy gray magnesian limestone	228-280	52
Very sandy grayish limestone passing below to sandstone mixed with shale or limestone (this layer is given as the Lower Magnesian Limestone in some records. It is probably the Mendota limestone)	280-305	25
Gray to white fine to medium grained slightly calcareous sandstone with some iron stained grains, shows brownish, shaley sandstone at 450-454; some white to green or very calcareous sandy limestone mixed with sandstone at 510-580 and 600-605.	305-605	300
Very calcareous pinkish shale with some fine sand	605-610	5
Sandstone like that above shale	610-715	105
Hard greenish gray shale mixed with sand at top. In the samples there is much red oxide of iron which probably comes from red layers in the shale. The shale is not very calcareous and is hard	715-745	30
Total depth		745

Lake Mills. The population of Lake Mills is 1,672. This village has a water supply and sewage system. The water supply is obtained from two 6-inch wells, 380 feet deep. The average daily pumpage is 62,000 gallons. The sewage, without treatment, empties into a branch of Rock river. About 75 per cent of the houses have both city water and sewer connections.

Waterloo. The population is 1,220. There are many artesian wells in this village, ranging in depth from 140 feet to 695 feet. The water rises to an altitude generally varying between 810 to 815 feet, about 10 or 15 feet below the level of the railroad track at the depot. Some of the best flows rise 10 and 12 feet above the surface. Most of the private wells range from 15 to 100 feet deep. The city supply, recently installed, is obtained from a well 120 feet deep.

The Waterloo flowing wells interfere somewhat with one another, and in order to get the best possible flow, wells must be packed properly. Packing usually is put in at about 160 feet depth. The fact that all the wells are not properly packed or cased has lowered the head and affected the flows considerably. In all the wells in the valleys no lime-

stone was reported. They pass through from 10 to 100 feet of drift, below which they are entirely in sandstone and calcareous sandstone beds.

Johnson Creek. The population is 425. A system of municipal water works and sewage was recently installed. The water supply is obtained from a well 333 feet deep, 8 in. diameter, cased 110 feet. The formations penetrated consist of 92 feet surface deposit and 241 feet of shale and sand rocks of the St. Peter and Lower Magnesian formations. About half the population use the supply, the average daily pumpage being about 7,000 gallons. The sewage is treated in septic tanks before being emptied into the Rock river.

Palmyra. The population is 649. At Palmyra a very deep well was sunk in 1865, in searching for oil. It is described by Chamberlin, in Geology of Wisconsin, Vol. II, p. 161. The following summarized section shows the thickness of formations passed through:

Summarized section of well at Palmyra.

Formation.	Thickness.
	Feet.
Drift	46
Galena-Trenton limestone	211
St. Peter sandstone	93
Lower Magnesian	62
Potsdam	338
Total depth	750

The large springs in the vicinity of Palmyra have already been referred to. Recently plans have been formulated for installing a system of waterworks for the village.

QUALITY OF THE WATER

The mineral analyses of the water supplies of Jefferson county are shown in the following tables. The Rock river water at Watertown Jct. and Jefferson is unusually hard water for a surface water in Wisconsin. These four analyses, probably represent the range in composition of the Rock river water. See mean analysis of the Rock river water at Rockford, Ill., p. 542. The Palmyra spring waters are hard calcium and magnesium carbonate waters and quite uniform in moderate content of mineral matter. The well waters, obtaining their supplies from the drift and the sandstone of the St. Peter and Upper Cam-

brian (Potsdam) formations, are also all hard calcium and magnesium carbonate waters of moderate mineral content, with only two notable exceptions. These two exceptions are waters of an artesian well at Palmyra, No. 32, depth 750 feet, and of an artesian well at Waterloo, No. 33, depth unknown, both of which are highly mineralized waters containing large amounts of sodium chloride, and therefore classed with "salt waters". The large amount of nitrates in No. 33 is worthy of note.

The city water supply of Ft. Atkinson No. 25 contains 2.08 pounds of incrusting solids in 1,000 gallons. The city water supply of Jefferson, No. 24, contains 2.28 pounds in 1,000 gallons, and the water from the C. & N. W. railroad well at Watertown, No. 12, contains 3.07 pounds in 1,000 gallons.

Mineral analyses of water in Jefferson County.

(Analyses in parts per million.)

	Rivers.				Springs.		
	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2) Aluminum and iron oxides ($Al_2O+Fe_2O_3$)	undet.	2.6	6.7	4.4 1.5	15.0	12.5	13.6
Aluminum oxide (Al_2O_3)	....	....	....	....	0.6	0.9	0.4
Iron (Fe)	....	....	....	....	0.4	0.6	0.3
Calcium (Ca)	67.2	43.4	32.6	66.6	59.6	65.3	68.3
Magnesium (Mg)	36.3	18.2	28.6	34.1	29.5	33.2	33.8
Sodium (Na) Potassium (K)	10.1	8.2	6.6	7.6	2.5 1.0	3.8 4.2	2.7 1.9
Carbonate radicle (CO_3)	186.9	114.3	119.1	133.0	159.9	172.8	179.2
Sulphate radicle (SO_4)	7.3	4.6	3.5	88.8	9.3	19.7	14.5
Chlorine (Cl)	6.1	3.9	6.8	6.4	1.6	5.0	3.0
Phosphate radicle (PO_4)	....	....	....	....	....	....	1.6
Total dissolved solids	324.	195.	204.	342.	279.	318.	320.

1. Rock River, Watertown Junction. Analyst, Chemist C. M. & St. P. Ry. Co., Nov. 4, 1903.
2. Rock River, Watertown Junction. Analyst, Chemist C. M. & St. P. Ry. Co., Sept. 14, 1891.
3. Rock River, Watertown Junction. Analyst, Chemist C. M. & St. P. Ry. Co., July 1, 1891.
4. Rock River, Jefferson. Analyst, G. M. Davidson. June 23, 1896.
5. Great Geyser Spring, Palmyra. Analyst, E. G. Smith.
6. House Spring, Palmyra. Analyst, E. G. Smith.
7. Mineral Park Spring No. 1, Palmyra. Analyst, E. G. Smith.

***Mineral analyses of water in Jefferson County*—Continued.**

(Analyses in parts per million.)

	Springs.						
	8.	9.	10.	11.	12.	13.	14.
Silica (SiO_2) / Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	13.9	14.4	13.0	15.0	15.3	15.6	20.
Aluminum oxide (Al_2O_3)	0.4	0.6	0.8	0.6	0.4	3.8	....
Iron (Fe)	0.3	1.4	2.9	4.8	4.1	....	....
Calcium (Ca)	70.5	71.3	71.9	61.4	59.4	58.4	90.8
Magnesium (Mg)	35.4	37.1	35.5	32.9	30.5	28.8	30.
Sodium (Na)	3.8	3.3	2.7	2.9	2.5	5.9 (Na + K)	26. (Na + K)
Potassium (K)	2.2	1.5	1.9	1.6	2.1		
Carbonate radicle (CO_3)	184.6	191.1	190.4	153.	168.8	153.5	220.
Sulphate radicle (SO_4)	12.6	16.7	17.7	6.2	4.3	14.1	14.2
Chlorine (Cl)	1.9	2.2	2.2	2.2	2.2	4.5	14.0
Phosphate radicle (PO_4)	1.3	1.6	0.1	0.5	0.5	....	....
Total dissolved solids	325.	341.	339.	281.	290.	284.	419.

	Drift or limestone.	St. Peter sandstone.			
	15.	16.	17.	18.	19.
Depth of well ... feet	55	187	290	189	230
Silica (SiO_2)	14.0	17.	9.5 (silica + oxides)	5.2 (silica + oxides)	6.6 (silica + oxides)
Aluminum and iron oxides ($Al_2G_3+Fe_2O_3$)	2.5	4.			
Iron (Fe)	....	....	....	0.5	....
Calcium (Ca)	64.9	77.1	95.3	51.1	101,0
Magnesium (Mg)	45.8	36.0	26.4	16.5	25.5
Sodium (Na)	14.1 (Na + K)	9. (Na + K)	12.1 (Na + K)	8.8	19.6 (Na + K)
Potassium (K)				0.4	
Carbonate radicle (CO_3)	158.6	200.	204.7	129.4	207.9
Sulphate radicle (SO_4)	90.6	27.6	6.0	0.5	49.7
Chlorine (Cl)	15.8	2.	18.6	....	1.5
Organic matter	....	....	1.8	5.9	....
Total dissolved solids	406.	373.	373.	212.	412.

8. Mineral Park Spring No. 2, Palmyra. Analyst, E. G. Smith.
9. Mineral Park Spring No. 3, Palmyra. Analyst, E. G. Smith.
10. Mineral Park Spring No. 4, Palmyra. Analyst, E. G. Smith.
11. Mineral Park Spring No. 5, Palmyra. Analyst, E. G. Smith.
12. Mineral Park Spring No. 6, Palmyra. Analyst, E. G. Smith.
13. Zenobia Spring, Palmyra. Analyst, G. Bode. Geol. of Wis, Vol. 2, p. 31, 1877.
14. Lowes Spring, Palmyra. Analyst, G. Bode. Geol. of Wis., Vol. 2, p. 31, 1877.
15. Well of C. & N. W. Ry. Co., Watertown. Analyst, G. M. Davidson, June 23, 1896. Flows 2,500 gals. per hour.
16. Magnetic well, Watertown. Analyst, G. Bode, Geol. of Wis, Vol. 2, p. 32, 1877.
17. Well of F. Miller, Watertown. Analyst, J. W. Tesch.
18. Buchert's Fountain Well, Watertown. Analyst, L. Brandecke, Geol. of Wis., Vol. 2, p. 161, 1877.
19. Railroad Well, Watertown. Analyst, Chemist, C. M. & St. P. Ry. Co.

Mineral analyses of water in Jefferson County—Continued.

(Analyses in parts per million.)

	St. Peter sandstone.						
	20.	21.	22.	23.	24.	25.	26.
Depth of well..........feet..	....	....	215	100	517	750	600
Silica (SiO_2)..................	undet.	undet.	undet.	19.3	10.9	11.4	8.0
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)..........				1.4	1.9	2.4	
Iron (Fe)..................	....	....	....	....	....	....	0.8
Calcium (Ca)..................	71.6	48.1	65.3	60.5	57.0	46.0	64.3
Magnesium (Mg)..............	38.3	46.9	35.3	31.0	28.6	31.9	34.8
Sodium (Na)................	24.7	30.6	7.7	10.0	3.5	4.1	5.7
Potassium (K)...............							1.0
Carbonate radicle (CO_3)....	225.9	213.7	181.8	173.5	142.8	132.6	174.5
Sulphate radicle (SO_4)......	6.6	11.9	11.9	8.4	25.6	24.7	7.7
Chlorine (Cl)..................	4.0	9.1	6.1	2.0	5.5	6.3	14.6
Free (CO_3).....................	....	....	....	9.0	....	....	....
Total dissolved solids...	371.	360.	308.	315.	276.	[illegible]	311.

	Upper Cambrian (Potsdam) sandstone.						
	27.	28.	29.	30.	31.	32.	33.
Depth of well..........feet..	1,145	400	1,145	1,200	1,345	750	....
Silica (SiO_2), Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)..........	1.1	2.2	5.3	undet.	2.7	18.8	24.
Aluminum oxide Al_2O_3)....	4.4	....	....	....	....	....	....
Iron (Fe)....................	3.4	....	....	....	....	....	....
Calcium (Ca)................	70.9	74.6	73.7	74.2	73.3	564.2	228.
Magnesium (Mg).............	32.4	35.0	34.2	34.2	33.2	233.1	121.
Sodium (Na)........	3.2	7.3	3.9	8.4	6.9	3,542.	311.0
Potassium (K)..............	1.1						55.
Carbonate radicle (CO_3)....	181.6	198.0	188.4	190.1	187.6	....	340.
Sulphate radicle (SO_4)......	15.1	11.7	14.9	16.2	15.9	764.0	163.6
Chlorine (Cl).........	4.9	2.7	2.6	7.2	3.1	6,461.0	657.6
Free (CO_3)......	....	....	....	....	....	....	....
Nitrate (NO_3)...............	....	....	....	....	....	....	469.
Lithium (Li).................	....	....	....	....	....	....	3.6
Total dissolved solids...	318.	332.	323.	330.	323.7	11,583.	2,368.

20. Well No. 1, Watertown. Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 2, 1895.
21. Well No. 2, Watertown. Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 2, 1896.
22. Well, Watertown Junction. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 4, 1903.
23. Well of C. Stoppenbach's Sons, Jefferson Junction. Analyst, V. Lehner, May 4, 1910.
24. Well of City Water Works, Jefferson. Analyst, G. M. Davidson, June 25, 1901.
25. City Artesian Well, Fort Atkinson. Analyst, G. M. Davidson, Jan. 21, 1902.
26. Well of City Water Works, Watertown. Analyst, E. G. Smith.
27. Well of City Water Works, Watertown. Analyst, W. W. Daniells.
28. Well, Watertown Junction. Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 13, 1892.
29. Well of City Water Works, Watertown. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 17, 1896.
30. City well of Watertown. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 4, 1903.
31. City well, Watertown. Analyst, Chemist, C. M. & St. P. Ry. Co., May 27, 1896.
32. Artesian well, Palmyra. Analyst, P. Schweitzer. Also contains Li. Cl. 5.8 and Na. Br. 5.1.
33. Artesian well, Waterloo. Analyst, G. Bode, Geol. of Wis., Vol. 2, p. 31, 1877.

JUNEAU COUNTY

Juneau county, located in the south central part of the state, has an area of 790 square miles, and a population of 19,569. About 67.1 per cent of the county is in farms, of which 47.1 per cent is under cultivation.

SURFACE FEATURES

The surface of Juneau county is a broad valley bottom plain in the northern two-thirds, and a deeply dissected upland plain in the southwestern one-third. The alluvial plain in the northern part contains isolated mounds and ridges of sandstone that generally rise from 100 to 200 feet above the general level of the plain. The hilly southwestern part, capped with the Lower Magnesian limestone on the uplands, is

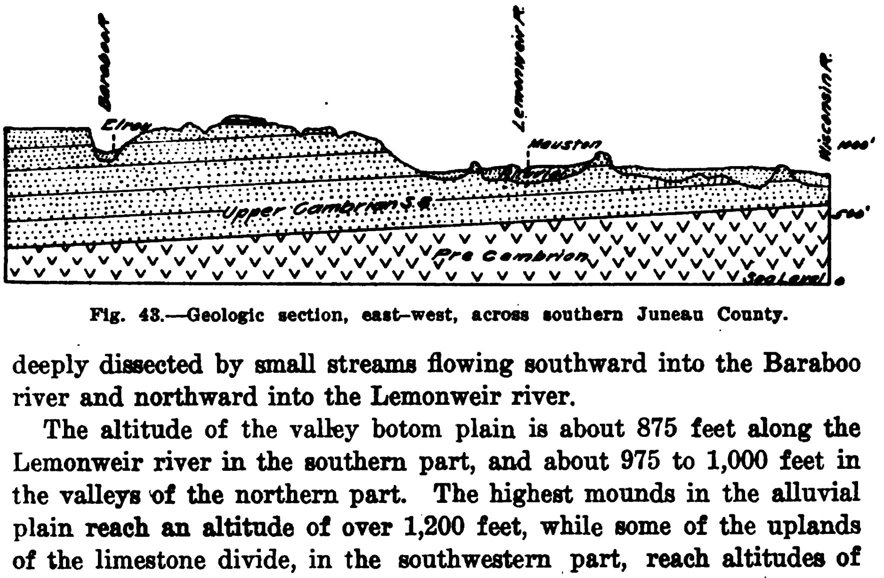

Fig. 43.—Geologic section, east–west, across southern Juneau County.

deeply dissected by small streams flowing southward into the Baraboo river and northward into the Lemonweir river.

The altitude of the valley botom plain is about 875 feet along the Lemonweir river in the southern part, and about 975 to 1,000 feet in the valleys of the northern part. The highest mounds in the alluvial plain reach an altitude of over 1,200 feet, while some of the uplands of the limestone divide, in the southwestern part, reach altitudes of over 1,300 feet.

The alluvial bottom lands are mainly sand and sandy loams, while the upland soils are generally silt loams.

GEOLOGICAL FORMATIONS

The geological formation of this county is mainly the Upper Cambrian (Potsdam) sandstone. The Lower Magnesian limestone extends over only a small area of the uplands in the southwestern part of the

county. A few small knobs of Pre-Cambrian quartzite occur at Necedah and in the vicinity of Babcock. The northeastern two-thirds of this county is a comparatively flat valley-bottom plain of alluvial sand formation, dotted here and there with isolated sandstone ridges and mounds. The alluvial sand and clay varies in depth from a few feet up to over 200 feet. The cross section, Fig. 43, illustrates the geological structure.

The thickness of the Upper Cambrian (Potsdam) sandstone and the Lower Magnesian limestone is variable on account of the extensive erosion of the strata. It is only where the sandstone is capped with the overlying Lower Magnesian limestone that the complete thickness of the former is preserved. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Juneau County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Lower Magnesian limestone	0 to 100
Upper Cambrian (Potsdam) sandstone	0 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the Upper Cambrian sandstone and the alluvial sand. In some places on the upland ridge of the southwestern part of the county, shallow wells are developed in the surface silt loam of loessial origin. The wells on the uplands, however, generally range from 100 to 250 feet in depth. Those on the sandy bottom lands are usually from 10 to 30 feet deep.

FLOWING WELLS

Flowing wells in the surface deposits, and from the underlying Potsdam sandstone, are an important source of water supply on low ground in the Baraboo river valley at Elroy and Wonewoc. The head of these flowing wells is usually only one or two feet above the surface of the curb, and is lowered rapidly in conformity with the slope of the valley down the river.

Flowing wells are not known to occur in the surface deposits along low ground in the Lemonweir valley, but it seems possible that such

may be developed in favorable localities. The flowing wells at Elroy and Wonewoc are described on the following page.

WATER SUPPLIES FOR CITIES AND VILLAGES

Elroy. This city, with a population of 1,729, situated on the Baraboo river, has a water supply and sewage system. The water supply is obtained from three 6-inch artesian wells, 88, 96 and 198 feet deep. The daily pumpage is about 140,000 gallons. About 80 per cent of the houses are connected with the system. The sewage is emptied without treatment into the river.

At Elroy about thirty artesian wells have been drilled along the flat north of the river, particularly in the northwest part of the city. Most of the wells along this valley pass through a black loam or marshy muck 6 to 14 feet deep, fine clay 10 to 20 feet deep, and then enter a bed of sand and gravel over sand rock. This bed of sand and gravel is the source of the artesian water, which rises to the surface, and in places 1 to 2 feet above. The water in this gravel and sand bed comes from the outcrop along the valleys and in part from the sandstone hills and from the underlying Upper Cambrian (Potsdam) sandstone upon which the sand and gravel rests.

The city water supply of Elroy is pumped from three wells sunk into the sandstone. The altitude of the curb is 936 feet. The pumps are attached direct to the casing of the well, thus forming a continuous suction pipe. The wells flowed before the ground around the pumping station was filled in, but now stands 3 feet below the present surface. The wells are arranged in an east-west direction at intervals of about 40 feet, the middle one being below the pumps.

Besides these deeper artesian wells, which formerly flowed, there are several shallow artesian flows from the soil overlying the rock. The water from all of them as stated, is obtained from a seam or gravel or layer of sand and gravel over rock, after passing through black muck and fine clay. The wells are affected by dry seasons and also slightly by heavy continued pumping at the waterworks plant, which seems to indicate that most of the supply at the water works plant comes from the underlying sandstone.

Wonewoc. The population of Wonewoc is 789. The city artesian well, 428 feet deep, has a normal head of 3 feet above the surface, and a flow of 60 gallons per minute. When pumped it furnishes 242 gallons per minute under a 14 foot head. The formations passed through in this well are as follows:

Log of Wonewoc city well.

Formation.	Thickness.
	Feet.
Alluvial clay and sand	54
Upper Cambrian (Potsdam) sandstone	374
Pre-Cambrian quartzite at bottom	....
Total	428

In the vicinity of Wonewoc are numerous flowing wells from 40 to 60 feet deep, in the alluvial sand in the valley of the Baraboo river. When the deeper city well is heavily pumped, most of the shallow wells cease to flow, one well 413 feet deep up the valley loosing 18 inches of head, and one 150 feet down the valley loosing 30 inches of head. These facts indicate that the flow from the alluvial sand very probably depends upon the pressure from the sandstone below.

Mauston. The population of Mauston is 1,701. The city water supply is obtained from six 6-to 8-inch wells from 143 to 220 feet deep in the Upper Cambrian sandstone. A sewerage system was installed a few years ago. The sewage is emptied, without treatment, into the Lemonweir river. The general water level is about 10 feet below the surface, and at the city wells only 7 feet below the surface. Private wells are generally driven from 30 to 100 feet in the alluvial sand formation.

New Lisbon. The water supply of New Lisbon, population 1,074, is taken from private wells, either drilled or dug, and generally vary from 20 to 50 feet in depth.

Necedah. The population of Necedah is 1,054. The city water supply obtained from the Yellow river is used for fire protection only. Private wells are generally from 20 to 40 feet deep in sandy alluvial formation. The alluvial sand and gravel at Necedah varies in thickness from 30 to 198 feet, and an abundance of water for a city supply could easily be obtained from this alluvial sand formation or from the sandstone below. The Pre-Cambrian granite, a short distance from the quartzite knobs, lies at a depth of 200 to 210 feet.[1]

The section of the C. & N. W. Ry. well at Necedah, drilled in 1911, generalized from description of samples made by F. T. Thwaites, is as follows:

[1] Bull. XVI, Wis. Geol. & Nat. Hist. Survey, p. 519.

Log of C. & N. W. Ry. well at Necedah.

Formation.	Depth.	Thickness.
Pleistocene (Alluvial sand)	Feet.	Feet.
Fine brownish yellow sand	10	....
Same as above	20	....
Gray clay, very calcareous and apparently without any grit	30	....
Same	40	....
Pinkish gray quartz sand	50	....
Fine grayish-white quartz sand with black specks	60	....
Same	70	....
Same	90	....
Course-grained white sand with specks of pink feldspar	100	....
Same as last	110	....
Same but finer grained	120	120
Upper Cambrian (Potsdam) Sandstone		
White sandstone	130	....
Fine-grained sandstone	140	....
Nearly white fine-quartz sandstone	150	....
Much coarser grained sandstone, color a light yellow	160	....
Very fine grained pinkish white pure quartz sandstone	170	....
Variable grain yellowish sandstone with specks of iron oxide	180	....
Same	190	....
Same	200	....
About the same as at 170, but coarser grained, pinkish white quartz	210	....
Same	220	....
Mainly very fine, but some medium grained pinkish white quartz	230	....
Rather fine but variable grained yellowish sandstone	240	....
Almost white quartz (sand) rather fine grained	250	....
Same, more yellowish	260	....
About the same as at 250	270	....
Extremely fine quartz sandstone, with occasional larger grains, nearly white in color	280	....
Same but slightly more yellowish	290	....
Slightly coarser grained but lighter colored	300	....
Fairly coarse grained quartz sandstone	310	190
Pre-Cambrian		
Light pinkish-gray "shale"	315	....
Weathered red granite	320	10
Total depth	....	320

QUALITY OF THE WATER

The mineral analyses of the water supplies of Juneau county are shown in the following table. The water obtained from the Yellow river and the sandy formation of the alluvial plains about Babcock, Mather, and Necedah is soft, while that obtained from the Upper Cambrian sandstone is hard water. In all the waters, lime greatly predominates over the sodium. All the waters are carbonate waters except that from the railroad wells at Elroy, Nos. 8 and 9, which are sulphate waters containing considerable alkalies. The large amount of organic matter in the city water supplies of Elroy, No. 7, indicates a contaminated source of supply at the time the sample was taken.

The soft waters of the Yellow river at Necedah, No. 4, contains 0.66 pounds of incrusting solids in 1,000 gallons. The soft water from the well of T. Williams at Necedah, No. 7, contains 0.74 pounds in 1,000 gallons, while the hard waters from the city wells at Elroy, No. 12, contains 1.36 pounds in 1,000 gallons, and the hard water from the railroad well at Elroy, No. 14, contains 2.78 pounds in 1,000 gallons.

Mineral analyses of water in Juneau County.

(Analyses in parts per million.)

	Creeks.			Rivers.		Surface deposits (Alluvial sand).	
	1	2	3	4	5	6	7
Depth of well............feet	....	19′ well and creek.	19′ well and creek.	....	....	10	70
Silica (SiO_2)..................	5.0	8.7	2.2	8.4	11.1	1.5	8.9
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)..........	....	....	....	0.5	5.6	....	1.0
Calcium (Ca)................	15.2	22.2	14.5	17.2	18.4	25.7	18.1
Magnesium (Mg).............	6.2	.6	7.0	7.0	7.1	6.7	9.8
Sodium and potassium (Na + K)......	7.6	4.1	3.4	0.7	2.3	13.6	6.6
Carbonate radicle (CO_3)	37.9	24.5	39.0	37.4	28.4	36.4	51.5
Sulphate radicle (SO_4)......	12.0	23.0	4.1	9.2	27.0	49.5	....
Chlorine (Cl)....	2.8	1.4	2.3	0.9	3.6	6.6	10.1
Organic matter..............	....	....	....	12.1	....	....	....
Total dissolved solids...	87.	84.	72.	81.	103.	140.	106.

	Surface Deposits (Alluvial sand—Continued.				Upper Cambrian (Potsdam) sandstone.			
	8	9	10	11	12	13	14	15
Depth of well..........feet	17.	67.	17.	17.	75 to 180	150.	150.	67.
Silica (SiO_2)................	7.0	3.2	8.0	2.9	14.4	16.4	20.1	undet...
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)....	......	......	......	......	5.6	3.2	1.8	....
Calcium (Ca)	18.8	14.1	23.0	11.5	33.4	48.0	68.6	26.5
Magnesium (Mg)	4.5	6.9	6.0	3.0	17.1	24.3	23.2	12.9
Sodium and potassium (Na + K)..................	9.8	6.2	10.3	7.6	21.5	11.9	19.4	13.5
Carbonate radicle (CO_3)..	3.7	44.2	......	6.8	115.5	80.9	61.0	77.4
Sulphate radicle (SO_4) ...	64.6	1.7	94.3	39.0	0.0	157.3	162.4	3.7
Chlorine (Cl)	5.8	1.2	4.2	3.9	7.8	18.4	27.4	10.4
Sol. matter	......	......	......	......	....	....	46.6	....
Total dissolved solids.	114.	77.	146.	75.	215.	360.	384.	144.

1. Small Creek, Lyndon. Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 1, 1890.
2. Webster Creek and well 19 ft. deep, New Lisbon. Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 2, 1890.
3. Webster Creek and well 19 ft. deep, New Lisbon. Analyst, Chemist C. M. & St. P. Ry. Co., April 1, 1890.
4. Yellow River, Necedah. Analyst, G. M. Davidson, Sept. 16, 1910.
5. Yellow River through city water works at Necedah. Analyst, G. M. Davidson, Oct., 1899.
6. Well of C. M. & St. P. Ry. Co., Necedah. Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 14, 1892.
7. Well of T. Williams, Necedah. Analyst, G. M. Davidson, Sept. 16, 1910.
8. Railroad well, Mather. Analyst, Chemist C. M. & St. P. Ry. Co., June 20, 1895.
9. Railroad well, Babcock. Analyst, Chemist C. M. & St. P. Ry. Co., Jan. 30, 1896.
10. Railroad well, Mather. Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 6, 1892.
11. Railroad well, Mather. Analyst, Chemist C. M. & St. P. Ry. Co., June 5, 1894.
12. Wells of City Water Supply, Elroy. Analyst, G. M. Davidson, Dec., 1900.
13. Well, C. & N. W. Ry. shops, Elroy. Analyst, G. M. Davidson, Nov. 23, 1909.
14. Two wells, C. & N. W. roundhouse, Elroy. Analyst, G. M. Davidson, July 15, 1907.
15. Well of C. M. & St. P. Ry. Co., New Lisbon. Analyst, G. N. Prentiss, Jan. 1, 1910.

KENOSHA COUNTY

Kenosha County, located in the southeastern corner of the state, has an area of 274 square miles, and a population of 32,929. About 90 per cent of the county is in farms, of which 74.2 per cent is under cultivation.

SURFACE FEATURES

The surface of Kenosha county is a gently undulating plain sloping eastward towards Lake Michigan. The valleys and ridges trend north and south, parallel to the lake shore. The drainage is mainly to the

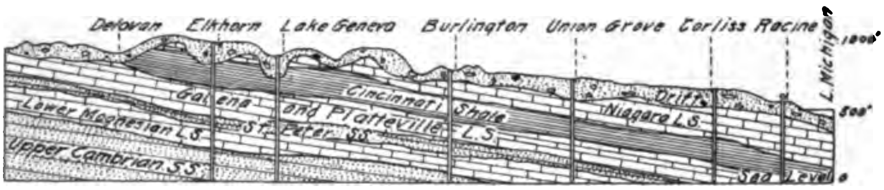

Fig. 44.—Geologic section, east-west, along the boundary of Kenosha and Racine and through central Walworth counties.

south into Illinois, through the Des Plaines river in the central part, and through the Fox river in the western part, both rivers being tributary to the Mississippi.

The surface of Lake Michigan is 580 feet above sea level. The altitude of the valley bottom of the Des Plaines river is about 700 feet, and of the Fox river, about 750 feet. The upland ridges in the eastern part of the county, adjacent to Lake Michigan, reach elevations of 700 to 740 feet; those in the central part reach 840 to 880 feet, and those in the western part reach over 900 feet. The usual range in altitude in all parts of the county rarely exceeds 150 feet, and is usually less than 100 feet.

GEOLOGICAL FORMATIONS

The rock formation immediately underlying the drift is the Niagara limestone. The geological structure of Kenosha, Racine and Walworth counties is illustrated in Fig. 44. The drift is generally from 50 to 100 feet deep, and in many instances it is 100 to 200 feet deep. The terminal moraine, consisting of abrupt hills and depressions, lies across the western part of the county, west of the Fox river.

The thickness of the Niagara is variable on account of the unequal erosion of the surface in preglacial time. The known maximum thickness is 280 feet in Kenosha, but it is quite probable that a thickness of 350 to 400 feet occurs where the drift is relatively thin on the upland ridges. The minimum thickness in pre-glacial valleys is probably not less than 50 or 100 feet.

The probable range in thickness of the geological formations in Kenosha county may be summarized as follows:

Probable range in thickness of formations in Kenosha County.

Formation	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone	100 to 300
Clinton formation	0 to 75
Cincinnati shale	150 to 200
Galena-Platteville (Trenton) limestone	250 to 350
St. Peter and Lower Magnesian formation	200 to 250
Upper Cambrian (Potsdam) sandstone	800 to 1000
Pre-Cambrian granite	....

PRINCIPAL WATER BEARING HORIZONS

The water bearing horizons for the shallow wells are the drift and the Niagara limestone, and for the deep wells the underlying St. Peter sandstone and the Potsdam sandstone.

FLOWING WELLS

Along the shore of Lake Michigan flowing wells are obtained at various places in the drift. In the vicinity of Winthrop Harbor, Ill., several flows have been struck in gravel at a depth of 126 to 130 feet. North of Kenosha in the valley of Pike River surface flows have been obtained. Similar flows can probably be obtained over much larger areas in this little valley.

Strong flowing wells from the deep-seated rock, the St. Peter and Upper Cambrian (Potsdam) sandstone, occur in Kenosha, the wells ranging in depth from 1,000 to 1,800 feet. The normal head above lake level appears to increase from about 80 feet in the St. Peter sandstone to as much as 120 feet near the base of the Potsdam sandstone. The head should increase with the distance from the lake, and hence deep-seated flowing wells may be expected along the valley of the Des Plaines river, up to altitudes of 750 feet, and in the valley of the Fox, up to altitudes of 800 feet.

WATER SUPPLIES FOR CITIES AND VILLAGES

Kenosha. Kenosha, situated on Lake Michigan, has a population of 21,371. The water supply is obtained from seven artesian wells, and from Lake Michigan, mostly from the latter source at present. The intake is 24 inches in diameter and extends 5,000 feet into the lake at a depth of 34 feet. Estimated daily capacity of the lake supply is 8,000,000 gallons; the average daily pumpage is 3,268,000 gallons. The sewage, without purification, empties into the lake. The analysis of the lake supply shows at times some contamination from sewage.

The underground water conditions at Kenosha are similar to those at Racine, although not as many wells have been drilled. The city formerly pumped its supply from seven artesian wells, ranging in depth from 1,300 to 1,850 feet. Most of the wells have a pressure of 25 to 30 pounds when first put in. The flow from the St. Peter sandstone was 250 gallons per minute, while that from the Potsdam was nearly 500 gallons per minute. Most of the water for the city supply is now pumped from Lake Michigan, and the wells are nearly abandoned. The pipes have partly rusted and there is considerable leakage. The artesian conditions here are favorable for a good supply of water from the St. Peter and Potsdam sources, and with little difficulty a good supply could be obtained equal to the Madison supply. However, the cost of pumpage would probably be greater than at Madison, and the mineral quality of the underground supply less favorable.

The section of the Pettet Malt House well is as follows:

Log of Pettet Malt Co. well, Kenosha.

Formation.	Thickness.
	Feet.
Drift	86
Niagara limestone	280
Cincinnati shale	180
Galena-Platteville (Trenton) limestone	340
St. Peter sandstone	160
Lower Magnesian limestone	80
Upper Cambrian (Potsdam) sandstone	477
Total	1,603

The log of the well of Louis Turner, 3 miles southeast of Kenosha, is as follows:

Log of L. Turner's well, 3 miles S. W. of Kenosha.

Formation.	Thickness.
	Feet.
Surface formation.	
Clay, sand, etc., no water	138
Niagara limestone.	
Hard, gray limestone, no water	249
Cincinnati shale.	
Bluish shale and some limestone, no water	213
Trenton limestone, water	173
Total	773

Ranney.—The log of the C. & N. W. Ry. well, one-half mile from Ranney, is as follows:

Log of C. & N. W. Ry. well at Ranney.

Formation.	Thickness.
	Feet.
Pleistocene.	
Brownish calcareous clay with some sand and pebbles	152
Niagara limestone.	
Gray magnesian limestone	260
Cincinnati shale.	
Calcareous shale	118
Galena-Platteville limestone.	
Gray dolomite limestone	180
Depth (unfinished)	710

Bristol.—Most of the water in the village of Bristol is pumped from wells 125 to 280 feet deep that reach to the Niagara limestone. The Bristol Creamery well is the deepest; it gets its supply from the St. Peter sandstone.

Log of Bristol creamery well.

Formation.	Thickness.
	Feet.
Drift	195
Niagara limestone	105
Cincinnati shale	70
Galena-Platteville (Trenton) limestone	311
St. Peter sandstone	70
St. Peter or "Potsdam" sandstone	149
Total depth	900

Somers.—Near Somers, Sec. 14, T. 2, R. 22, is the deep well of Herman Kreuder, which shows an interesting section, as follows:

Log of Herman Kreuder's well, Somers.

Formation.	Thickness.
	Feet.
Pleistocene.	
Drift	171
Niagara.	
White limestone	15
Blue limestone	15
Cherty limestone	100
Clinton.	
Reddish purple limestone	32
Iron ore	18
Cincinnati.	
Blue shale	50
Soft blue shale	150
Galena-Platteville—(Trenton)	
Limestone	50
Porous limestone (water)	100
Blue shaly limestone	170
Sand	10
Hard gray limestone	20
St. Peter.	
White sandstone	10
Total depth	911

This record is valuable in showing the Clinton iron ore beds at the base of the Niagara limestone. The Clinton group certainly occurs elsewhere, but it is usually not recognized where common churn drills are employed. This section also shows the bed of sand that is so often encountered near the base of the Galena-Platteville (Trenton) limestone.

QUALITY OF THE WATER

The mineral analyses of the various waters of Kenosha county are shown in the following table. The waters of the surface deposits and the Niagara limestone are both soft and hard waters, while that from the deep wells in the St. Peter and Potsdam sandstones are more highly mineralized and should be classed as very hard water. All the waters analyzed from Kenosha are somewhat unusual, as compared with waters from other parts of the state, in their relatively high content of sodium and potassium as compared with calcium and magnesium. All the waters from the shallow wells in the surface deposits and the Niagara limestone and the spring at Bristol, in respect to chemical character should be classed as sodium waters, while those from the deep wells from the St. Peter and Potsdam sandstones, should be classed as calcium waters. The waters from the shallow wells are carbonate waters, while that from the deep wells contain about equal proportions of carbonates and sulphates.

The spring water, No. 2, and the well waters, Nos. 4, 5, and 6, are much softer waters than Lake Michigan water, on account of their lower content of calcium and magnesium. The water from the well at Basset, No. 6, is a remarkably soft water, even softer than some of the soft spring waters from the northern part of the state. These very soft sodium carbonate waters are all of the same type, and from their occurrence at Bassett, Bristol, Truesdell, and Bain, appear to be characteristic of a coarse sand and gravel bed overlying the Niagara limestone or from within the upper beds of the limestone, over a considerable part of the county.

The water from Lake Michigan, at Kenosha, contains 1.09 pounds of incrusting solids in 1,000 gallons; the soft sodium water from the 224-foot well at Basset, reaching 92 feet into Niagara limestone, contains only 0.17 pounds of incrusting solids in 1,000 gallons; that from the shallow drift well at Bain, 140 feet deep, contains 1.02 pounds in 1,000 gallons; while that from the deep well at Bain, 1,639 feet deep, contains 3.76 pounds in 1,000 gallons.

Mineral analyses of water in Kenosha County.

(Analyses in parts per million.)

	Lake Michigan.	Spring.	Surface deposits (Drift).			
	1.	2.	3.	4.	5.	6.
Depth of well........ feet..	....	....	45	72	130	140
Silica (SiO_2)........	5.4	13.7			14.5	19.2
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$).....	1.8	....	2.4	2.1	1.9	1.5
Iron (Fe)........	....	2.6	....	....	....	....
Calcium (Ca)........	32.9	18.4	46.3	47.6	16.5	17.3
Magnesium (Mg)........	10.6	9.1	31.4	32.8	11.7	16.8
Sodium and Potassium (Na+K)........	5.2	87.3	48.0	43.6	70.2	62.0
Carbonate radicle (CO_3)..	68.6	.107.5	147.2	150.4	139.2	128.3
Sulphate radicle (SO_4)....	15.1	89.5	97.2	91.5	0.7	19.6
Chlorine (Cl)........	5.3	4.5	1.8	2.4	6.7	9.7
Organic matter........	6.	....	....	....	....	....
Suspended matter........	10.	....	....	....	....	....
Total dissolved solids..	145.	333.	374.	370.	261.	274.

1. City supply—Lake Michigan direct, Kenosha. Analyst, Dearborn Drug & Chem. Co., Dec. 4, 1911.
2. Bristol Soda Spring at Woodworth. Analyst, G. A. Mariner.
3. Railroad well at Truesdell. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 18, 1890.
4. Railroad well at Truesdell. Analyst, Chemist, C. M. & St. P. Ry. Co., Dec. 12, 1894.
5. Well on Rogers farm at Bain. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Aug. 3, 1905.
6. Well of contractor at Bain, 6 in. diameter. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Aug. 7, 1905.

Mineral analyses of water in Kenosha County—Continued.

(Analyses in parts per million.)

	Niagara limestone.	St. Peter and Upper Cambrian sandstone.		
	7.	8.	9.	10.
Depth of well .... feet	224	1,650	1,365	1,639
Silica (SiO_2)	8.9	8.2	7.7	19.3
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	1.3	....	1.5
Aluminiumoxide (Al_2O_3)	....	....	0.5	....
Iron (Fe)	....	....	0.4	....
Calcium (Ca)	3.0	111.9	93.8	107.3
Magnesium (Mg)	1:3	20.0	27.8	33.9
Sodium and Potassium (Na+K)	149.7	38.2	36.1	35.3
Carbonate radicle (CO_3)	195.5	168.1	152.	170.8
Sulphate radicle (SO_4)	8.9	128.1	136.0	183.4
Chlorine (Cl)	2.1	8.0	8.9	6.2
Phosphate radicle (PO_4)	....	....	trace	....
Total dissolved solids	369.	494.	458.	558.

7. Well of C. & N. W. Ry. Co. at Bassetts, 6 in. diameter. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Mar. 27, 1900.
8. Artesian well of "Park City Water Co." at Kenosha. Analyst, G. M. Davidson, June 23, 1891.
9. City well at Kenosha. Analyst, E. G. Smith.
10. Well of C. & N. W. Ry. Co. at Bain, 6 to 12 in. in diameter. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Mar. 8, 1906.

KEWAUNEE COUNTY

Kewaunee county, located in the eastern part of the state, on Lake Michigan, has an area of 327 square miles and a population of 16.784. About 97.3 per cent of the county is in farms, of which 68.5 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is an undulating plain mainly sloping southeast towards Lake Michigan. In the northwestern corner, bordering on Green Bay, is a relatively steep slope to the northwest.

The central part of the county is drained by the Kewaunee river, the northeastern part by the Ahnapee river, and the southern part by the Twin rivers.

The Kewaunee river has a prominent valley throughout most of its course. The dissected upland plain is slightly modified by a belt of

hummocky drift hills, a continuation of the Kettle Range, extending northeast, through the central part of the county.

The altitudes range from 581 feet, the level of the lake, to a maximum of 900 or 950 feet in the western and northern parts of the county. The general level of the highest parts of the county is between 850 and 900 feet. The main valley of the Kewaunee river does not reach above 200 feet above the lake level. The most prominent reliefs are the high banks along the shore of Lake Michigan in the eastern part and on Green Bay in the northwestern part, which reach from 100 to 200 feet above the level of the lake within 3 or 4 miles from the shore.

GEOLOGICAL FORMATIONS

With the exception of the northwest corner bordering on Green Bay where the Cincinnati shale is present the county is underlain by the Niagara limestone. The drift and other surface deposits overlie the limestone in variable but considerable thickness. The geological structure is illustrated in Fig. 32.

Adjacent to the shore of Lake Michigan is a considerable thickness of lacustrine clay and beach gravels, associated with the glacial drift. The thickness of the surface deposits is variable, but has a known maximum thickness at Algoma of 140 feet. It is very probable, however, that the thickness of the surface deposits greatly exceeds this in various parts of the county.

The Niagara limestone, as elsewhere in the eastern part of the state, contains occasional strata of fine-grained shaly limestone which exert a marked influence on the movement of underground waters. The thickness of the Niagara formation is variable on account of erosion. The known maximum thickness at Algoma is 485 feet. The usual thickness of the formation within the county is probably between 200 and 500 feet.

The Cincinnati formation consists of fine-grained impervious clay and shale beds, and outcrops only along the Green Bay shore at the base of the Niagara limestone ledge. From 50 to 60 feet of the formation is exposed above the level of the bay. The thickness of this formation where uneroded is known to be 518 feet at Algoma, and from 500 to 550 feet in Sec. 7 near Dyckesville. A short distance north of Kewaunee county, in Door county, along the shore of Green Bay, in Sec. 24, T. 27, R. 22 E., two deep wells were drilled to the St. Peter sandstone, and in these wells the thickness of the Cincinnati shale was reported to be 516 and 540 feet, see pp. 311–12.

The description of drillings mainly of the Cincinnati shale, from the new city well of Algoma, drilled in 1912, samples and record sent by J. O. Posson, and drillings described by F. T. Thwaites, is as follows:

Log of well of City Water & Light Plant, Algoma, Wisconsin.

Formations.	Depth.	Thickness.
Surface	0–27	27
Niagara limestone	27–512	485
Cincinnati shale	512–1,030	518
Gray—blue shale	730	
Soft Gray—blue shale and one piece of limestone	740	
Soft bluish shale	825	
Same described as "soft and sticky until it strikes the air when it hardens"	850	
Hard blue shale	870	
Soft blue shale	915	
Bluish shale	930	
Galena—Platteville (Trenton) limestone	1,030–1,225	195
Gray limestone	1,125	
Gray limestone finely pulverized	1,185	
Same	1,200	
Same	1,225	
St. Peter sandstone	1,225–1,336	111
Fine gray sand	1,230	
Lower Magnesian red shale	1,336–4"	
Total depth	....	1,336.4

The approximate thickness of the geological formations in Kewaunee county may be summarized as follows:

Approximate thickness of formations in Kewaunee County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone	0 to 550
Cincinnati shale	300 to 550
Galena-Platteville (Trenton) limestone	150 to 250
St. Peter and Lower Magnesian	150 to 250
Upper Cambrian (Potsdam) sandstone	400 to 500
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING FORMATIONS

The usual sources of the ground-water supply are the surface deposits of glacial drift, lacustrine and beach deposits, and the Niagara limestone.

Abundant water can generally be obtained from the surface formations at depths varying from 10 or 15 feet up to 100 feet. There are many shallow dug wells on the upland area from 20 to 40 feet in the

drift. Drilled wells, however, are generally deeper and usually reach 100 to 150 feet, either wholly in the drift or some distance into the underlying rock.

Wells obtain an abundant supply of good clear water in the Niagara limestone, the source of supply being in the open fractures and seams. The water level varies from a few feet below the surface in the valley bottoms to 100 feet below the surface on the broad upland areas, and somewhat deeper on the narrower and higher ridges.

The Cincinnati shale is unimportant as a source of water supply, but within the area of this formation, adjacent to Green Bay, abundant water is found at the contact of the shale and overlying surface gravels.

The deep-seated strata of sandstone are drawn upon only in the deep city well recently drilled in Algoma. (See under Algoma).

FLOWING WELLS

Flowing wells very probably occur in various parts of Kewaunee county, in the surface deposits and at the contact with the underlying rock. Flowing wells of this type occur at Kewaunee, at depth of 40 to 60 feet, the water rising to 7 feet above lake level.

Flowing wells from the St. Peter and Upper Cambrian (Potsdam) sandstone formations are very probably not obtainable along the shore of Lake Michigan and Green Bay in Kewaunee county. Only one well reaching into the St. Peter sandstone has been drilled, namely the new city well in Algoma, which developed a head of 22 feet above the surface of Lake Michigan. This well, though it reached 111 feet into the St. Peter sandstone, apparently receives its flow from the lower part of the Niagara limestone, at a depth of 465 feet. The explanation of the unfavorable artesian conditions of the sandstone formations is given on page 80.

WATER SUPPLIES FOR CITIES AND VILLAGES

Kewaunee.—This city located on the shore of Lake Michigan has a population of 1,839. The city has no water works system and no sewage system. The surface sewage empties into the river. Cesspools are allowed. Private wells are from 20 to 60 feet deep. The W. F. Wainniger Co. have a flowing well, 49 feet deep in drift, that flows 4½ feet above ground. At Kewaunee, in the depression formed by the Kewaunee river where it enters the lake, are several flowing wells, deriving their flows at the surface of the limestone or a few feet within it. The water in these flowing wells rises to seven feet above the lake.

Algoma.—The population of Algoma, located on Lake Michigan, is 2,082. The city water supply is mainly obtained from wells, one deep artesian well and one shallow well. The shallow well has a depth of 16 feet, and diameter of 21 feet, and daily capacity of 100,000 gallons. The artesian well has depth of 1,336 feet, diameter of casing 6 in. and daily capacity of 125,000 gallons. The deep artesian well has a head of 22 feet above lake level, source of flow at 465 feet in the Niagara limestone and flows under its own head into a reservoir, from which it is pumped into the transmission system. The average daily pumpage is 50,000 gallons. About 200 houses are connected with the city water works, about 60 per cent of the population being supplied. Only about 30 houses are connected with the sewage system. The sewage, without treatment, is emptied into the Ahnapee river. The city water works is connected with a 12 inch pipe extending 360 feet into the lake, used in case of fire emergency and for use in boilers.

The private wells in the city are generally shallow and range in depth between 20 and 40 feet. The log of the deep city well is given on page 403.

In the village of Casco, population 350, are many wells from 20 to 30 feet in the drift.

A well 540 feet deep, belonging to Joe Vandermessen of Dyckesville, in Sec. 7, T. 25, R. 23, on the shore of Green Bay, is reported to be drilled all the way in blue shale, which is very thick at this place, is very impervious, and yields no water.

QUALITY OF THE WATER

No complete mineral analyses of the water of Kewaunee county are available, but judging from the character of the geological formations, it seems very likely that the supplies obtained are very generally very hard waters of moderate mineral content.

A chemical sanitary analysis of the water from the new city artesian well of Algoma, drilled in 1912, was made, sample being taken when well was drilled to depth of about 1,000 feet (though it is the opinion of the water works superintendent that the water came from a depth of 465 feet, near the base of the Niagara limestone) and showed a total mineral content of 368 parts per million. The content of chlorine was 5.22. The total solids consisted of calcium, magnesium and sodium carbonates. No salt water was encountered in drilling this well and the water now is without taste.

The mineral analyses of the water from Lake Michigan, an important source of supply for cities located along the lake, are cited on page 221.

La Crosse County

La Crosse County, located in the western part of the state, has an area of 475 square miles, and a population of 43,996. About 89.9 per cent of the county is in farms, of which 54 per cent is under cultivation.

SURFACE FEATURES

The surface of La Crosse county is broken and hilly. The level land is mainly confined to the principal valley bottoms and the summits of the upland areas. The La Crosse river, flowing westward across the central part of the county, has throughout a flat bottomed valley from one to three miles wide. The bottom lands along the Mississippi and the Black rivers occupy considerable areas in the western part. The altitudes generally range from 650 to 750 feet along the prominent valley bottoms, to 1,300 and 1,360 feet on the relatively level narrow-topped uplands. The soils in the valleys are mainly sands and sandy loams, and upon the uplands, either sandy loams or silt loams of the loessial type.

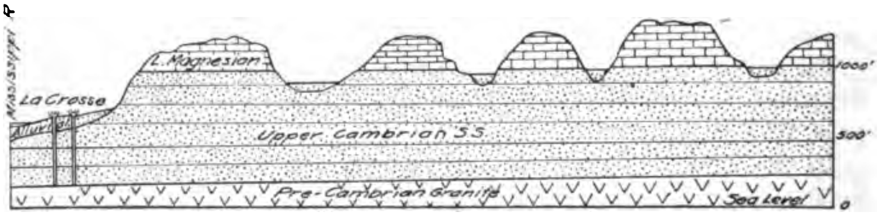

Fig. 45.—Geologic section, east-west, across southern La Crosse County.

GEOLOGICAL FORMATIONS

The indurated geological formations are the Upper Cambrian (Potsdam) sandstone, and the Lower Magnesian limestone, the latter being confined to the summits of the uplands in the southern and north central parts of the county. The limestone in the north central part forms the summit of the divide between the drainage of the La Crosse and Black rivers. Alluvial sand and gravel fills the valley to a probable maximum depth of 200 to 250 feet. A fairly abundant deposit of loess loam, from 5 to 10 feet thick overlies the uplands. The geological structure is illustrated in Fig. 45.

The thickness of the Upper Cambrian (Potsdam) sandstone and the Lower Magnesian limestone is variable on account of the extensive erosian of these formations. The complete thickness of the Upper Cambrian is preserved only where overlain by the limestone formation. The limestone reaches its maximum thickness on the highest upland areas. The Pre-Cambrian granite floor lies at a depth of 520 feet below the valley bottom at La Crosse. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in La Crosse county.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Lower Magnesium limestone	0 to 200
Upper Cambrian (Potsdam) sandstone	400 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the Upper Cambrian sandstone and the alluvial sands and gravel. The limestone is an important source of supply only on the uplands in the southern part of the county. In the larger valley bottoms most wells reach abundant water in the surface formations at depths of 20 to 40 feet. In the narrow valleys many of the wells are from 30 to 50 feet deep. On the limestone uplands the wells are much deeper, most of them being 100 to 200 feet in depth and very generally reaching down some distance into the underlying sandstone.

FLOWING WELLS

Considerable interest was aroused 30 or 40 years ago concerning the artesian conditions in La Crosse.

The first well was drilled in 1876 on the corner of Fourth and Main streets. A flow was not obtained because of the high altitude. Since then it has been repeatedly demonstrated that artesian flows can be obtained from the sandstone on lower ground in and about the city. The original head was 20 to 30 feet above the Mississippi river, about 660 to 670 above sea level. Near the center of the city, where most of the wells are located, the head is now very low, due to the great number of wells and to the heavy pumping at the water-works to supply

the 20 public artesian fountains in various parts of the city. The mills and breweries also draw heavily upon the artesian supply and tend to keep the heads below the surface, except on low ground. It has been observed that when new wells are sunk between Tenth Street and Mississippi river, where all of the flowing wells in La Crosse have been drilled, the new wells get their supply partially at the expense of the older ones. Within this limited area the overdrafts are noticeable, but not so outside.

South of La Crosse, on the Mormon Cooley road, there are flowing artesian wells 400 to 500 feet deep on many of the farms. Some of these wells are on the lowlands of the Mississippi and generate power enough to drive hydraulic rams which raise the water to the houses and barns.

These artesian flows are not merely confined to the Mississippi river banks, but are struck on comparatively high ground in the valley basin, and also at points one or two miles east of the river, on the banks of the streams that empty into the Mississippi. The rich farming lands of the "coolies" are also supplied with flowing wells, which penetrate the sandstone to some depth. Usually, however, the wells do not enter the Upper Cambrian (Potsdam) sandstone deep enough to get a flow, even where the land is low enough.

The present heads of the wells increase and reach a height of 650 to 700 feet above tide, a short distance south of La Crosse. This is doubtless partly due to the high range of bluffs to the east. A safe estimate would place the average head south of La Crosse at about 680 feet above tide.

The absence of flowing wells at West Salem and Bangor in the La Crosse valley, although flowing wells are abundant farther up the valley at Rockland and Sparta in Monroe county, is referred to under Monroe county, page 472. The explanation of the absence of favorable conditions for the development of flows about West Salem and Bangor is given under the general description of the flowing wells in La Crosse valley on pages 67–9.

WATER SUPPLIES FOR CITIES AND VILLAGES

La Crosse.—La Crosse, located on the east bank of the Mississippi river, at the mouth of the Black and the La Crosse rivers, has a population of about 30,417. It is located on a flat, sandy alluvial formation with relatively high uplands of sandstone capped with lime-

stone, lying immediately to the east. The city supply until very recently was obtained from the Mississippi river, from a point about 200 feet from the bank, where the water is about 8 feet deep. In times of high water the river is turbid with sediment, causing the intake to clog. The water was not purified and has been used principally for industrial purposes and fire protection. The pumpage is about 3,000,000 gallons per day. About 60 per cent of the houses are connected with the water supply. The drinking water is obtained mainly from shallow wells and a few artesian wells. About 30 per cent of the houses are connected with the sewage system. The sewage is emptied, without purification, into the river below the intake pipe.

After considerable agitation extending over a period of several years the city finally decided to change its source of water supply from the Mississippi river to a ground water supply. At the present time (March 1913) the new system is being installed on the low ground adjacent to the La Crosse river in the northeast part of the city. The new supply[1] is obtained from the alluvial sand and gravel deposits which attain a general thickness of 110 to 200 feet in the valley at La Crosse. The water is obtained from a system of 5 groups of 4 wells each; each well being 10 in. in diameter, cased 100 feet with 25 feet of No. 20 Johnson strainers attached to the end of the casing. The well groups are spaced about 800 to 900 feet apart. The wells in each group are placed about 100 feet apart. Each group of wells is to be operated by a vertical electric driven centrifugal pump of 2,000,000 gallons capacity, against a head of 40 feet, delivering water into a 1,000,000 gallon reservoir at the pumping station in Myrick Park. See also the table, page 136.

A 20 day test of one of the 10 in. wells was made with the following result:

Summary Test of One 10 in. Well January 10th to 30th, 1912.

Time—Jan. 10th morning to Jan. 30th evening	21½ days
Total water pumped	11,397,900 gals.
Average rate, gals. 24 hours	531,000 gals.
Average rate gals. per minute	372 gals.

[1]Data obtained from plans submitted by Messrs. Alvord & Burdick.

Observations of Rate and "Drawdown"

Date.	Rate, gals. per min.	Drawdown in ft.	Specific capacity.
Jan. 16	473	12.9	36.6
Jan. 23	390	10 6	36.8
Jan. 23	495	13.7	36.1
Jan. 25	473	13.4	35.8
Jan. 30	525	14.75	35.6
Average			36.2

NOTE:—Water recovered its original level 40 to 48 hours after pump stopped.

Upon the results of this test it is calculated that this system of 20 wells would have a capacity of 10,000,000 gallons per day. However, there will be interference in the well supplies when all the wells are continuously drawn upon, and hence the total daily capacity will probably be much less than 10,000,000 gallons for any extended period.

In determining the amount of available ground water supply within the new well tract, observations were made by engineers to determine the general direction and rate of underground flow. For this purpose the ground water level in about 30 wells located in North La Crosse and in South La Crosse north of Main St. was measured. The observations were made as rapidly as possible on April 9th and 10th, 1911 when both the Mississippi and La Crosse rivers were higher than normal.

The observations made on the ground water levels indicated as would be expected, that in North La Crosse the flow of ground water is almost directly westward from the La Crosse to the Black river, the La Crosse river being about 14 feet higher than the Black where it emerges from the bluffs, the distance between the two rivers at this place being about one and one-third miles. In general the data indicated that the flow was toward the west in North La Crosse, and southwest in South La Crosse. In the vicinity of the Interstate Fair Grounds the ground water is apparently being replenished by a flow coming out from Miller's coulee.

There are many private wells in the city that are from 10 to 30 feet deep that get their supplies from the sand formation along the Mississippi river. The water in these shallow wells may easily be contaminated and in many places it is dangerous to drink it. Good pure water is obtainable from private artesian wells, and from many public fountains supplied by the waterworks from the two deep city artesian

wells. In 1899 these two wells were tested and yielded 763,200 gallons in 24 hours. The wells are only a few feet apart and readily interfere with one another. Within a block northeast of the city wells are also the Listman Milling Company's well, from which about 200,000 gallons are pumped daily, and the Edison Light & Electric Company's well, which has not been used recently. At Gund's brewery are three deep wells, the water being raised from one of the wells by means of an air lift 140 feet down in the well. The other two wells have the suction pipe attached to the casing and furnish about 650,000 gallons per day. These wells are so close together that they interfere with one another, and if the well, containing the air lift, is worked to its full capacity the other two will be of litle value. The water stands 23 feet below the surface at present and the above pumpage causes the water to lower about 15 feet in the well. By pumping from greater depth, as is done at Madison, the capacity of one of these wells might be made to equal approximately a million gallons per day.

For a complete record of the first artesian well drilled in 1876 see Geology of Wisconsin, Vol. 4, page 60. In this well the surface sand has a thickness of 170 feet. Samples of the city wells drilled in 1889 may be seen at the office of the City Engineer of La Crosse. The log of one of the city wells and of the well at Grand Crossing, owned by the Chicago, Burlington and Quincy Railway Company, are given below. These records may be taken as representative records of the La Crosse wells. Many of the deeper wells strike granite, and all show the bottom of the old valley to be at a considerable depth below the present surface.

Logs of artesion wells in La Crosse.

Formation.	City well drilled in 1889.	C. B. & Q. R. R. well.
	Thickness.	Thickness.
	Feet.	Feet.
Alluvial sand:		
River sand	146	91
Coarse pebbles	8	53
Quicksand	0	9
Upper Cambrian (Potsdam) sandstone:		
White sandstone	150	56
Yellow sandstone	50	87
Yellow sandstone (coarse)	25	111
Brownish sandstone (coarse)	105	28
White lumpish sandstone (hard)	40	36
Pre-Cambrian granite	2	at bottom.
Total depth	526	471

Onalaska.—At Onalaska, population 1,146, a few miles north of Grand Crossing and La Crosse, the artesian conditions are the same as at North La Crosse and Grand Crossing. The public water supply is obtained from two flowing wells 8 inches in diameter and 470 and 493 feet deep. The supply is obtained from the sandstone, and the average daily pumpage is 45,000 gallons. About 50 per eent of the houses are connected with the system.

The log of the Onalaska city well as determined from examination of samples by F. T. Thwaites is as follows:

Log of Onalaska city well.

Formation.	Depth.	Thickness.
	Feet.	Feet.
Alluvial Sand.		
Sand. No sample	0— 40	
Course reddish sand	80—105	
Coarse gravel. Water at river level	105—125	
Fine gray sand (gravel)	125—148	148
Upper Cambrian. (Potsdam) sandstone	148—180	
Same, coarser grained	180—200	
Very fine grained shaly gray sandstone	2 0—250	
Gray calcareous shale	250—285	
Coarse white sandstone	285—305	
Same	305—335	
Finer grained sandstone	335—365	
Brown shale	365—370	
Medium grained white sandstone	370—410	
Very coarse white sandstone, some pink feldspars	410—440	
Same. (Thought to be within 30 feet of the granite.)	440—445	297
Total depth		445

West Salem.—West Salem, population 840, has a public water supply obtained from one well 8 inches in diameter and 400 feet deep. The formations penetrated consist of 120 feet of sand and the remainder the Upper Cambrian (Potsdam) sandstone. About 33 per cent of the population use the public supply. A sewage system is installed, with which about 40 houses are connected. The sewage has outlet through settling basins to the La Crosse river. The private wells vary in depth from 8 feet, near the river, to 30 and 40 feet further back from the stream. Most of the wells do not enter rock. On the limestone ridges, in the vicinity of West Salem, toward the south, the wells are much deeper, 100 to 200 feet in depth, but in the small valleys they are from 30 to 50 feet in depth.

In the County Asylum well a strong flow was obtained at a depth

of 23 feet, from fissures in the Potsdam sandstone. The fissure strikes in a northeast-southeast direction. The present head of the water is reported at 44 feet below the surface.

Section of W. A. Houghton well, West Salem.

Formation.	Thickness.
	Feet.
Red clay	20
Sand and clay	40
Blue clay	10
Sand	42
Potsdam sandstone	18
Total depth	130

Conditions about West Salem are about the same as at La Crosse. The old valley is filled with sand and clay to a depth of 100 to 200 feet, but the surface is overlain by thick beds of clay so the water from sand beneath these clay beds is as pure as from the sandstone. Thus far no artesian flows have been obtained, and it is likely that no flows will be struck on the lowest ground in this vicinity, see page 68.

Bangor.—This village, population 692, like West Salem, mainly depends upon private wells for water. The wells generally vary between 10 and 40 feet, in sand formations, and increase in depth farther back from the river. R. B. Johns[1] reports that granite was struck in the railroad well at depth of 400 feet, about 345 feet above sea level.

For water supply for public use the village depends upon the Hussa Brewing Company's two 7-inch artesian wells, 135 feet deep. About 60 houses are connected with the public water supply.

QUALITY OF THE WATER

The available mineral analyses of the water supplies in La Crosse and the city water supply at Onalaska are shown in the accompanying tables. The water is generally hard water from both river and groundwater sources though the river water is much lower than the ground water in hardness. The river water from the Mississippi and La Crosse have about the same content of mineralization as Lake Michigan water. The water of Black river is soft water and appreciably lower in mineral content than the water of the Mississippi and La Crosse rivers.

[1] R. B. Johns, Thesis, Univ. of Wis., 1900.

The mineralization of the water supplies in the surface sand is much the same as that from the underlying sandstone. The table of analyses shows a number of mineral analyses of water from the city test wells at a depth of 100 feet. The samples analyzed in Sept. 1911 are very uniform in chemical composition and show a low normal content of chlorine. However, the high content of chlorine and nitrates in samples 15 and 17 in table analyzed in April, 1908 indicate a contaminated source of supply at that time. If those analyses in the table that appear to be of polluted supply are not considered in the general averages, the content of mineral in water of the surface sand deposits would be about 268 parts per million compared with about 282 parts per million in the indurated sandstone. The similiarity in the composition of the water from the surface deposits and that from the rock is probably due to the fact that most of the water in the surface deposits in the valleys is ground water from the sandstone bluffs. It may be stated as a general observation that the alluvial sands in the broad level alluvial tracts in central and northern Wisconsin are very generally characterized by soft waters. On the other hand, the alluvial sands in narrow valleys adjacent to the sandstone uplands capped with limestone are very generally characterized by waters mineralized to the same extent as water in the adjacent sandstone uplands.

In general the water at La Crosse from the Mississippi river contains about one pound of incrusting solids in 1,000 gallons, while that from the ground water supplies contains about two pounds in 1,000 gallons.

Mineral analyses of water in La Crosse County.

(Analyses in parts per million.)

	Rivers.						
	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2)	11.2	9.5	9.9	2.6	....	....	....
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	1.6	1.5	4.2	1.5	undt.	undt.	undt.
Calcium (Ca)	30.1	21.8	35.0	28.8	13.1	21.3	14.1
Magnesium (Mg)	12.4	7.9	8.1	13.8	5.8	8.8	5.0
Sodium and potassium (Na+K)	7.6	6.4	9.8	4.2	4.5	5.0	7.1
Carbonate radicle (CO_3)	76.0	47.1	72.3	76.4	33.2	45.8	35.4
Sulphate radicle (SO_4)	6.4	13.0	16.3	7.7	4.8	13.0	4.2
Chlorine (Cl)	7.0	6.8	2.4	1.7	4.1	7.2	4.1
Organic matter	24.0	....	....	....	....	....	....
Nitrate radicle (NO_3)	....	....	1.0	....	....	....	....
Total dissolved solids	152.3	114.0	159.0	136.7	65.5	101.1	69.9

	Rivers.		Surface deposits.				
	8.	9.	10.	11.	12.	13.	14.
Depth of well ... feet	....	....	25	30	30	35	80
Silica (SiO_2)	15.0	16.00	....	....	....	....	9.0
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	....	....	4.1	undt.	undt.	undt.	22.4
Iron (Fe)	.07	.39	....	....	....	....	....
Calcium (Ca)	40.0	33.00	52.4	72.2	69.2	64.7	56.7
Magnesium (Mg)	14.0	13.00	16.3	21.4	21.2	21.7	31.4
Sodium and potassium (Na+K)	10.0	10.00	22.0	30.6	28.6	16.6	4.6
Carbonate radicle (CO_3)	92.6	74.80	126.0	98.0	98.1	117.9	145.3
Sulphate radicle (SO_4)	18.0	24.00	17.6	164.8	151.4	51.5	34.5
Chlorine (Cl)	1.6	3.70	12.6	undt.	undt.	25.5	2.2
Nitrate radicle (NO_3)	1.4	1.80	....	....	....	....	....
Suspended matter	7.9	106.00	....	....	....	....	....
Total dissolved solids	192.67	176.69	251.0	386.5	368.5	297.9	306.1

1. Mississippi River at La Crosse. City Water Supply. Analyst, Dearborn Drug & Chemical Co., Nov. 12, 1907.
2. Mississippi River at La Crosse. City Water Supply. Analyst, W. G. Kirchoffer.
3. Mississippi River at La Crosse. City Water Supply. Analyst, Floyd Davis.
4. La Crosse River at La Crosse. Analyst, Dearborn Drug & Chemical Co.
5. Black River at North La Crosse. Analyst, G. N. Prentiss, Sept. 3, 1907.
6. Black River at North La Crosse. Analyst, G. N. Prentiss, Sept. 12, 1910.
7. Black River at North La Crosse. Analyst, G. N. Prentiss, June 24, 1904.
8. Mississippi River at Minneapolis, Minn. Mean of 35 analyses. U. S. Geological Survey. U. S. P. No. 236, p. 75, 1906–7.
9. Mississippi River at Moline, Ill. Mean of analyses. U. S. Geological Survey. U. S. P. No. 236, p. 117, 1906–7.
10. Well of C. M. & St. P. Ry. Co. at La Crosse. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 1, 1890.
11. Well of C. M. & St. P. Ry. Co. at North La Crosse. Analyst, G. N. Prentiss, Nov. 4, 1900.
12. Well of C. M. & St. P. Ry. Co. at North La Crosse. Analyst, G. N. Prentiss, Nov. 15, 1900.
13. Well of C. M. & St. P. Ry. Co. at North La Crosse. Analyst, G. N. Prentiss, Feb. 28, 1907.
14. Copeland Well, Myrick Park. Analyst, Davis, 1905.

Mineral analyses of water in La Crosse County—Continued.

(Analyses in parts per million.)

	Surface deposits.							
	15.	16.	17.	18.	19.	20.	21.	22.
Depth of well...............feet..	100	100	100	100	100	100	100	100
Silica (SiO_2).......	13.7	2.6	2.8	3.7	1.6	4.0	5.5	6.8
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	1.9	1.5	6.9	2.1	2.1	2.1	2.0	2.0
Calcium (Ca).....................	84.7	28.8	37.7	54.9	59.1	58.6	57.5	55.4
Magnesium (Mg)...	19.0	13.6	21.0	27.0	30.7	29.3	28.6	23.1
Sodium and potassium (Na+K).	45.4	4.2	65.5	5.0	5.0	6.9	9.1	6.2
Carbonate radicle (CO_3).........	102.0	76.4	115.0	144.0	156.4	157.2	157.0	150.0
Sulphate radicle (SO_4)...........	12.4	7.7	12.8	18.0	18.2	18.3	15.5	13.6
Chlorine (Cl)......................	48.8	1.7	75.0	1.7	3.5	3.5	3.5	3.5
Nitrate radicle (NO_3)............	8.1	....	8.2	....	....	....	....	....
Total dissolved solids.	286.0	186.5	354.4	256.4	276.6	279.9	278.7	265.6

	Surface deposits.			Upper Cambrian (Potsdam) sandstone.				
	23.	24.	25.	26.	27.	28.	29.	30.
Depth of well...............feet..	100	100	110	471	471	498	500	526
Silica (SiO_2)......................	5.5	6.0	2.6	1.7	24.0	2.0	6.0	9.7
Aluminum and iron oxides $Al_2O_3+Fe_2O_3$)	2.0	2.1	4.3	....	3.0	1.9	16.0	6.6
Aluminum oxide (Al_2O_3)........	....	....	....	2.6	....	....	....	....
Calcium (Ca).....................	57.0	54.7	56.5	52.4	66.3	60.2	39.9	86.6
Magnesium (Mg)................	28.7	27.9	28.7	31.9	25.3	22.3	16.0	21.7
Sodium and potassium (Na+K).	8.8	5.8	5.6	4.4	2.2	8.6	25.2	8.9
Carbonate radicle (CO_3).........	154.9	146.6	143.4	147.1	130.1	135.2	71.9	173.0
Sulphate radicle (SO_4)......	17.6	16.0	6.9	16.6	55.9	24.9	32.9	22.7
Chlorine (Cl)......................	3.5	3.5	3.5	6.8	....	7.0	19.3	8.0
Nitrate radicle (NO_3)............	....	....	....	....	....	....	15.1	1.9
Total dissolved solids	278.0	262.6	246.5	263.5	306.8	262.14	242.3	339.1

15. City Test Well No. 1, La Crosse. Analyst, Dearborn Drug & Chem. Co. Apr. 24, 1908.
16. City Test Well No. 2, La Crosse. Analyst, Dearborn Drug & Chem. Co. Apr. 9, 1911.
17. City Test Well No. 2, La Crosse. Analyst, Dearborn Drug & Chem. Co. Apr. 24, 1908.
18. City Test Well No. 2, La Crosse. Analyst, Dearborn Drug & Chem. Co. Sept. 9, 1911.
19. City Test Well No. 3, La Crosse. Analyst, Dearborn Drug & Chem. Co. Apr. 28, 1908.
20. City Test Well No. 4, La Crosse. Analyst, Dearborn Drug & Chem. Co. Sept. 9, 1911.
21. City Test Well No. 5, La Crosse. Analyst, Dearborn Drug & Chem. Co. Sept. 9, 1911.
22. City Test Well No. 6, La Crosse. Analyst, Dearborn Drug & Chem. Co., Sept. 9, 1911.
23. City Test Well No. 7, La Crosse. Analyst, Dearborn Drug & Chem. Co., Sept. 9, 1911.
24. City Test Well No. 8, La Crosse. Analyst, Dearborn Drug & Chem. Co. Sept. 9, 1911.
25. Well at Rubber Mills, La Crosse. Analyst, Dearborn Drug & Chem. Co., Sept. 10, 1911.
26. Well of C. B. & Q. Ry. Co. at La Crosse. Analyst, Chemist, C. B. & Q. Ry. Co.
27. Well of C. B. & Q. Ry. Co. at La Crosse. Analyst, Chemist, C. B. & Q. Ry. Co.
28. City Water Supply, Onalaska. Analyst, Dearborn Drug & Chemical Co., March 12, 1910.
29. Well of Michel Brewing Co. Analyst, Murphy, Sept. 18, 1911.
30. City well at Club House, La Crosse. Analyst, Floyd Davis. 1905.

Lafayette County

Lafayette County, located in the southwestern part of the state, has an area of 634 square miles, and a population of 20,075. About 92.8 per cent of the county is in farms, of which 78.2 per cent is under cultivation.

SURFACE FEATURES

The surface of Lafayette county is a deeply trenched upland plain, the uplands rising to a general elevation of 1,100 feet above sea level. Above this general elevation the Platte Mounds, in the northwestern part of the county, rise about 300 feet, the highest mound reaching an altitude of 1,430 feet. The Pecatonica river has a flat-bottomed valley generally less than half a mile wide. The main valleys are generally narrow, with continuous slopes upward from the streams. The altitude of the valley bottom of the Pecatonica ranges between about 780 feet below Gratiot to 880 feet at the Iowa county line. The greater part of the land of the county is therefore less than 300 feet above the valley bottoms.

GEOLOGICAL FORMATIONS

The geological formations are the same as those in southern Grant and Iowa counties. The Platteville-Galena limestone (Trenton), forms the main bed rock of the undulating uplands. The Upper Cambrian (Potsdam) sandstone is nowhere exposed at the surface. Along the principal valleys, such as the Pecatonica and the Fever rivers, only the Platteville-Galena limestone and the St. Peter sandstone usually occur, and occasionally the Lower Magnesian formation. Southeast of Shullsburg the Maquoketa shale (Cincinnati) group forms the summit of the upland ridges. The valleys are filled with abundant alluvial deposits, and upon the uplands loess loam is commonly present. In the southeastern corner of the county are a few scattered boulders of glacial drift. The geological structure is illustrated in Fig. 46.

The surface deposit, mainly consisting of loess, on the uplands, is relatively thin, usually ranging between 0 to 5 or 10 feet in thickness. In the valley bottoms, however, the river deposits of sand and gravel probably attain a maximum thickness of 200 to 300 feet. The thickness of the rock formations is also variable, on account of the ex-

tensive erosion of the strata. The complete section of the Platteville and Galena beds, is preserved only where this formation is protected by the overlying beds of Maquoketa shale, in the Platte Mounds and in the southern part of the county. Where the section of the Galena-

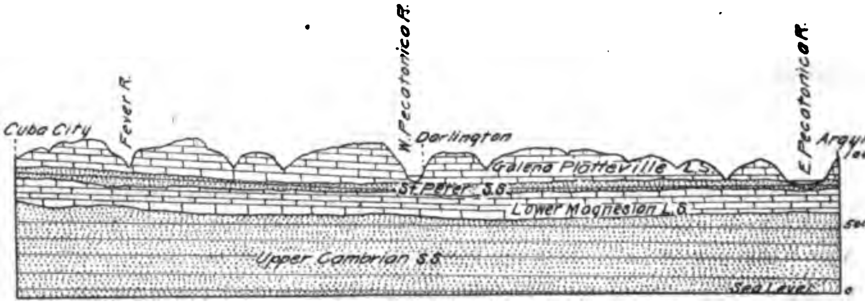

Fig. 46.—Geologic section, east-west, across central Lafayette County.

Platteville (Trenton) formation is complete the usual thickness is from 250 to 300 feet. The complete thickness of the Cincinnati (Maquoketa) shale is preserved only where protected by the overlying Niagara limestone in the Platte Mounds. The approximate range in thickness of formations in this county may be summarized as follows:

Approximate range in thickness of formations in Lafayette County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone (only on Platte Mounds)	0 to 100
Cincinnati shale (Maquoketa)	0 to 160
Galena-Platteville (Trenton) limestone	0 to 300
St. Peter and Lower Magnesian	100 to 250
Upper Cambrian (Potsdam) sandstone	750 to 1100
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the Platteville-Galena limestone and the St. Peter sandstone. Some wells obtain their supply from the Lower Magnesian, but no records of wells penetrating to the Upper Cambrian (Potsdam) are known in the county. The wells throughout the county generally vary from 20 to 40 feet deep along the valleys up to 250 feet upon the limestone uplands.

The groundwater supplies of Lafayette county are controlled by the same beds of shale at the base of the Galena and Platteville limestone

and at the base of the St. Peter sandstone as in Grant county. The water level in most of the lead and zinc mines in the southwestern part of the county is 60 or 70 feet, and only rarely over 100 feet, below the surface. Some wells in the eastern part of the county, as on the uplands near Darlington and Blanchardville, are 200 to 250 feet deep, probably getting their supplies either from the St. Peter or Lower Magnesian formations.

SPRINGS

No flowing wells are known to occur in the county, but springs are common where the shale strata outcrop in the valley. A well known mineral spring is located in Darlington, and the public supply of this city is also obtained from a large spring issuing from the base of the Platteville limestone.

WATER SUPPLIES FOR CITIES AND VILLAGES

Darlington.—The population of Darlington is 1,808. This city has a water supply system, the water being obtained from a spring in the city limits. The spring has a diameter of 27 feet and depth of 21 feet, the water standing 8 feet below the surface. About 75 per cent of the houses are on the water system. No sewage system is installed. About 20 per cent of the houses have cess pools. Private wells in the city are reported at 20 to 150 feet in the rock, the deepest wells probably drawing supply from the Lower Magnesian limestone. The well of James Smith, near Darlington, has a depth of 213 feet in Lower Magnesian, and that of Charles Johnson, 220 feet, reaching the St. Peter sandstone.

Shullsburg.—The population is 1,063. The city water supply is from an open well, 10 feet in diameter, 38 feet deep, from the bottom of which a 6-inch well, 265 feet deep, is drilled. The average daily pumpage is 30,000 gallons. The city has no sewage or disposal plant.

Blanchardville.—The population of Blanchardville is 643. Private wells in Blanchardville are reported to be from 40 to 200 feet deep. This village has a public water supply and partial sewage system. The water supply is obtained from one well, 6 inches in diameter, 75 feet deep in the surface sand and gravel. The average daily pumpage is 24,000 gallons. The sewage is emptied, without purification, into the East Pecatonica river.

QUALITY OF THE WATER

The available mineral analyses of the water supplies of Lafayette county are shown in the following table. The waters from the surface deposits, the Galena-Platteville (Trenton) limestone, and the St. Peter sandstone are either hard or very hard waters. The waters from the St. Peter sandstone appears to show about the same degree of hardness as that from the limestone. Water obtained from the Maquoketa (Cincinnati) shale is likely to show a higher content of mineral than that obtained from the other formations of the county. All the waters analyzed are carbonate waters with calcium and magnesium as the important constituents.

The water from the railroad well at Ipswich, No. 6, contains 2.59 pounds of incrusting solids in 1,000 gallons, and that from the "300 foot well" at Shullsburg, No. 7, contains 2.76 pounds in 1.000 gallons.

Mineral analyses of water in Lafayette County.

(Analyses in parts per million.)

	Spring.	Surface deposits or Galena-Platteville limestone.			Galena-Platteville limestone.		St. Peter sandstone.
	1.	2.	3.	4.	5.	6.	7.
Depth of well..........feet..	....	16	35	....	21	111	300
Silica (SiO_2).............	10.4				10.4	15.4	1.
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$) .. .	....	18.3	2.2	8.5	....	1.0	6.3
Aluminum oxide (Al_2O_3)...	1.1	....	....	....	11.2	....	....
Iron (Fe).............	.5	....	....	....	0.5	....	....
Calcium (Ca)........	59.4	67.5	70 1	90.7	59 3	64.3	68.6
Magnesium (Mg)............	45.8	32.1	34.9	61.2	45.7	35.7	40.2
Sodium (Na)...............	4 5	9.1	6.4	27.7	4.7	1.3	11.3
Potassium (K)............	.8				0.7		
Carbonate radicle (CO_3)....	200.9	186.7	191.5	287.5	201.5	168.0	180.4
Sulphate radicle (SO_4)......	4.0	7.4	9.7	1.5	3 9	26.7	34 1
Chlorine (Cl)	4.1	1.5	2.8	41.5	4.1	2.0	17.1
Phosphate radicle (PO_4)....	.. ..	....	....	....	Trace.	....	....
Total dissolved solids..	332.	323.	318.	519.	34 2.	314.	359.

1. Badger Mineral Spring at Darlington.
2. Railroad well at Calamine. Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 28, 1891.
3. Railroad well at Gratio. Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 6, 1891.
4. Railroad well at Shullsburg. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 3, 1891.
5. City water supply at Darlington. Analyst, W. W. Daniells.
6. Railroad well at Ipswich. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Jan. 22, 1909.
7. Well, "300 feet deep" Shullsburg. Analyst, Dearborn Drug & Chem. Co., Mar. 22, 1905.

LANGLADE COUNTY

Langlade County, located in the northeastern part of the state, has an area of 855 square miles, and a population of 17,062. About 23 per cent of the county is laid out in farms, of which 37.1 per cent is under cultivation.

SURFACE FEATURES

The southwestern part of the county, in the vicinity of Antigo, and westward, is quite level, while the southeastern, eastern and northern parts are relatively quite undulating on account of the terminal moraine hills that characterize those portions. The northeastern part is drained by the Wolf river flowing southeast, while the western part is drained by the Eau Claire and Pine rivers flowing southwest.

The altitudes above sea level generally range between 1,400 feet about Antigo to 1,800 to 2,000 feet in the undulating hills on the divide in the northern part.

The soil is generally a loam, with subsoils of gravel and sand over most of the county.

GEOLOGICAL FORMATIONS

The principal formation is the glacial drift and associated alluvial sand and gravel plains, which quite effectually cover the older rock formations. In only a few places are there outcrops of the underlying granitic formations. The drift is generally from 50 to 200 feet thick.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing formation is the surface deposit of drift, gravel and sand. This formation very generally furnishes an abundant supply at relatively shallow depths of 20 to 50 feet. Very few wells in the county are over 100 feet deep.

WATER SUPPLIES FOR CITIES AND VILLAGES

Antigo.—Antigo, the county seat, has a population of 7,196. It is located on a plain, with a sandy, gravelly subsoil, and sandy loam surface soil. The elevation of the railroad station is 1,483 feet. The

thickness of the sand and gravel formation is 58 feet, as shown by the boring of the city well.

The city supply was originally drawn from a single large open well, 20 feet in diameter and 25 feet deep, dug through 5 feet of gravelly clay loam and 20 feet of white sand and gravel. Recently a new system was installed, consisting of 8 tubular screen wells, 6 inches in diameter with 5 foot screen, laid out 8 feet below the surface, and one rectangular well, 22 feet wide, 80 feet long, and 5 feet deep. This system is laid adjacent to Spring Brook Creek and approximately on the same level. The average daily pumpage is about 720,000 gallons. The city sewage is emptied, without purification, into the creek.

Some years ago there was an unsuccessful attempt made to sink an *artesian* flowing well at Antigo. The well was put down with a churn drill to a depth of nearly 400 feet, wholly in granite below a depth of 58 feet. Only a very small amount of water was obtained from the granite.

QUALITY OF THE WATER

The water of Langlade County, as shown by the analyses, is mainly soft water. The analyses, Nos. 2 to 4 of the Antigo well waters, may be considered typical for the formation about Antigo. The high content of chlorine in No. 3 is probably due to a contaminated source of supply. The hard water, No. 5, obtained from the glacial drift at Elton, may indicate the presence of limestone in the drift of that locality, as the source of the drift in that vicinity is from the eastern part of the state, where limestone is abundant. All the waters are likely to be carbonate waters with calcium predominating.

The soft water of Summit Lake contains only 0.47 pounds of incrusting solids in 1,000 gallons. The city water works well of Antigo, Analysis 2, contains 0.74 pounds of incrusting solids in 1,000 gallons, while the hard water at Elton, No. 6, contains 2.02 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Langlade County.

(Analyses in parts per million.)

	Lake.	Surface deposits (alluvial).				Glacial drift.
	1.	2.	3.	4.	5.	6.
Depth of well	....	25	27	?	126	24
Silica (SiO_2)	5.6	17.4	10.6	18.6	12.3	17.8
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	1.3	2.5	3 4	3.4	1.8	0.3
Calcium (Ca)	11.3	17.1	23.8	22.2	34.8	53.9
Magnesium (Mg)	3.8	7.2	7.5	10.5	18.7	25.4
Sodium and potassium (Na+K)	3.1	3.2	26.4	5.6	1.3	5.8
Carbonate radicle (CO_3)	14.3	41.7	42.2	58.4	98.5	140.1
Sulphate radicle (SO_4)	10.4	2.7	22 9	3.6	....	7.1
Chlorine (Cl)	4.6	4.9	38.3	7.0	2.0	7.0
Organic matter	12.5	....	....	....	13.0	....
Total dissolved solids	64.	97.	175.	129.	169.	257.

1. Summit Lake at Summit Lake. Analyst, G. M. Davidson, July 24, 1909.
2. Well of City Water Works, at Antigo. Anayst, G. M. Davidson, March 1896.
3. Drive well in Antigo. Analyst, G. M. Davidson, Aug., 1902.
4. Well at Antigo. Analyst, Dearborn Drug & Chem. Co., June 7, 1909.
5. Railroad well at Malcolm, 4 ft. diameter. Analyst, G. M. Davidson, C. & N. W. Ry. Co., Aug., 1902.
6. Railroad well at Elton, 17 ft. diameter. Analyst, G. M. Davidson, C. & N. W. Ry. Co., May 28, 1907.

Lincoln County

Lincoln County, located in the north central part of the state, has an area of 885 square miles, and a population of 19,064. About 21.6 per cent of the county is laid out in farms, of which 26.8 per cent is under cultivation.

SURFACE FEATURES

The surface is mainly a gently undulating plain. The kettle moraine, a belt of hummockly drift hills extends east and west across the central part, north of Wood river, and in the vicinity of Schultz Spur and Dunfield. The northern half of the county is usually very gently sloping, while the southern and southeastern part is more undulating.

The principal river is the Wisconsin, flowing southward through the central portion. The soil is generally a loam, with the exception of the northeastern part, where sandy loam and sandy soil prevails.

The altitudes generally range between 1,250 and 1,600 feet.

GEOLOGICAL FORMATIONS

Most of the county, except the southeastern part, is quite effectually covered with glacial drift and the associated alluvial sands and gravels. In the southeastern part of the county, where the surface is characterized by relatively prominent valleys, the drift overlying the granite is relatively thin in many places. Rock rapids occur at Merrill and at Grandfather Falls, and at many places along the tributaries of the Wisconsin, such as the Prairie, the Pine and the Copper rivers.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing formation is the surface formation of drift and alluvial sand and gravel, which very generally furnishes an abundant supply at a relatively shallow depth of 20 to 50 feet. Only rarely are the wells over 100 feet in depth. Where the underlying crystalline rock is near the surface it must be relied upon to furnish local supplies. While an abundant supply is not usually obtained from the crystalline rock, very generally an amount can be obtained sufficient for stock and domestic use on the farms. The water in the crystalline rock is wholly within the fractured zones, and the more the rock is fractured the larger is the supply obtainable. Where the crystalline rock is massive, and free from fractures, very little or no water is obtainable.

WATER SUPPLIES FOR CITIES AND VILLAGES

Merrill. Merrill, the county seat, located at the junction of the Prairie and Wisconsin rivers, has a population of 8,689. The city is located upon gravelly and sandy terraces of the river formation. The city water supply is obtained from the Prairie river, at a point where it is about 100 feet wide and from 2 to 5 feet deep, the water being taken in at the bank through a screen. The average daily pumpage is 967,000 gallons. In the spring and fall, during times of high water, the water is purified by a set of gravity filters having a capacity of 1,500,000 gallons per day. Sulphate of aluminum is used to remove the suspended matter and vegetable stain. The sewage, without treatment, is discharged into the Wisconsin river. The private wells in the city vary in depth from 10 to 90 feet.

An insufficient supply for the city from 17 six inch wells, put down 25 feet in the drift, was abandoned a few years ago. It is reasonable

to believe, however, that an adequate groundwater supply could easily be obtained at Merrill by a properly arranged system of wells at depth of 50 to 100 feet in the sand and gravel.

Tomahawk. This city has a population of 2,907. It is located on the Wisconsin river, at an elevation of 1,450 feet. The formation is a sand plain of glacio-alluvial origin approximately level and about 10 or 15 feet above the level of the river above the Tomahawk dam.

At Tomahawk the supply is obtained from springs located near the edge of a swamp. The system of waterworks was installed in 1891. A well 30 feet in diameter was sunk to a depth of 18 feet over the site of the spring, and when not pumped the water flows over the top of the well. The swamp is filled with numerous springs, and a small stream of water flows by the well, almost touching its walls, clearly showing the natural drainage in the direction toward the well. The supply of water is limited, and only by judicious pumping can a sufficient supply be obtained. The average daily pumpage is about 165,000 gallons. A second shallow well was recently put in.

About 70 per cent of the houses have water and sewage connections. The sewage, without treatment, is discharged into the Wisconsin river.

Most of the private wells are drive wells, ranging in depth from 10 to 80 feet. Many private wells vary from 10 to 20 feet deep in sand and gravel. A few wells have a depth of 50 to 80 feet, being cased down nearly to the bottom in order to obtain a deeper and more pure supply.

At Irma, wells in the drift are from 10 to 40 feet deep. At Heafford Junction the wells are from 20 to 40 feet in sand and gravel. At Gleason and Bloomville the wells are generally from 20 to 40 feet in the drift.

QUALITY OF THE WATER

The water supplies of Lincoln County, as shown by the analyses in the following table are usually either very soft water, or soft water, as should be expected from the shallow depths and non-calcareous character of the water-bearing formations from which the supplies are obtained. The water of analysis No. 11 is probably contaminated, as indicated by the high content of chlorine.

Mineral analyses of water in Lincoln County.

(Analyses in parts per million.)

	Rivers.		Springs.				
	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2) ..... Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)....	0.9	undt....	2.7	7.0	2.7	2.7	undt....
Calcium (Ca)	23.1	7.4	5.6	6.4	5.9	5.6	38.0
Magnesium (Mg)............	8.4	2.8	2.3	2.5	2.5	2.8	10.0
Sodium and potassium (Na + K).................	10.4	5.4	6.6	7.7	9.7	7.1	5.4
Carbonate radicle (CO_3)....	64.8	19.1	22.2	24.0	26.8	22.3	81.7
Sulphate radicle (SO_4)......	1.9	4.1	0.7	1.0	trace ..	0.7	4.3
Chlorine (Cl)	4.0	4.1	0.8	1.2	1.0	0.8	4.1
Total dissolved solids...	113.	48.	41.	50.	49.	41.	143.

	Surface deposits.				
	8.	9.	10.	11.	12.
Depth of well.......................feet	41.	14.	28.	23.	30.
Silica (SiO_2)........ Aluminium and iron oxides ($Al_2O_3 + Fe_2O_3$)....................	21.7	4.2	0.5	2.2	8.2
Calcium (Ca)...........................	24.6	18.4	15.8	25.8	24.3
Magnesium (Mg).......................	2.8	6.2	5.7	11.7	10.1
Sodium and potassium (Na + K).......	2.7	2.0	12.8	19.4	11.3
Carbonate radicle (CO_3)....	48.9	48.1	43.6	78.8	57.1
Sulphate radicle (SO_4)..................	0.9	1.5	15.1	5.1	26.4
Chlorine (Cl)	3.5	2.0	0.9	29.6	1.4
Total dissolved solids...............	100.	77.	94.	173.	139.

1. Prairie River, City Water works, Merrill, Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 7, 1896.
2. Wisconsin River, Tomahawk, Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 22, 1904.
3. Tomahawk Spring, Tomahawk, Analyst, Chemist C. M. & St. Ry. Co., July 16, 1904.
4. Spring, City Water Works, Tomahawk, Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 15, 1892.
5. Spring, City Water Works, Tomahawk, Analyst, Chemist C. M. & St. P. Ry. Co., June 7, 1894.
6. Spring, City Water Works, Tomahawk, Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 9, 1896.
7. Spring at Harts' Spur, Merrill, Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 6, 1904 .
8. Railroad well at Tomahawk, Analyst, Chemist C. M. & St. P. Ry. Co., Dec. 24, 1887.
9. Private well at Merrill, Analyst, Chemist C. M. & St. P. Ry. Co., Mar. 24, 1888.
10. Private well at Irma, Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 9, 1896.
11. Well of C. M. & St. P. Ry. Co., Merrill, Analyst, C. M. & St. P. Ry. Co., Oct. 1, 1889.
12. Well of C. M. & St. P. R. Co., Irma, Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 15, 1892.

MANITOWOC COUNTY

Manitowoc county, located in the eastern part of the state, on Lake Michigan, has an area of 590 square miles and a population of 44,978. About 93.3 per cent of the county is in farms of which 68.7 per cent is under cultivation.

SURFACE FEATURES

The surface is a moderately undulating plain, rising to a common level in the central and western part, and sloping towards Lake Michigan in the eastern part. The county is drained by the Manitowoc river flowing east to the lake in the central and western part, and by the East and West Twin rivers in the northeastern part. The valley of the Manitowoc is quite prominent throughout its course. The Kettle Range of drift hills extend northeast across the central part of the county. The land along the East and West Twin rivers is gently sloping, the land in the northeastern part of the county being much lower than that in the western part. The altitude of the valley bottom of the Manitowoc river in the western part is between 800 and 850 feet above sea level and the upland ridges are generally less than 200 feet above the valley.

GEOLOGICAL FORMATIONS

The only rock formation is the Niagara limestone, over which usually lies a variable amount of glacial drift. The geological structure is illustrated in Fig. 24, showing a cross section along the southern border of the county. Besides the glacial drift, there are gravel deposits and lacustrine clays in considerable thickness adjacent to the lake shore. In the western part of the county red clay is abundant over the upland areas. The Kettle range consists of hummocky drift hills that are usually 50 to 100 feet above the surrounding lower land, being much less prominent in relief than the range farther south in Sheboygan and Washington counties.

The Niagara limestone is generally effectually covered with the surface deposits, but in many places along the abrupt ridges or along streams the formation is well exposed. Many quarries are developed along the limestone ridges for the purposes of burning lime.

An interesting record probably showing the complete thickness of the Niagara formation is that of the well of the Northern Grain Co. located near Manitowoc. The following is the record of this well, with the geologic correlations of the various formations by E. O. Ulrich of the U. S. Geol. Survey, from samples submitted:

[1]Record of well of Northern Grain Company, in Sec. 31, T. 19, R. 24. Near Manitowoc)

Formation.	Depth.	Thickness.
	Feet.	Feet.
Drift:		
Yellow sand	3- 6	3
Hard yellow clay	6- 20	14
Medium-hard blue clay	20- 85	65
No sample	85- 90	5
Niagara:		
Medium hard to very hard brownish and grayish limestone	90-148	58
Hard, sandy limestone and dark gray shale	148-180	32
Medium hard brownish and grayish limestone	180-195	15
Very hard white limestone	195-230	35
Hard gray limestone: water stands within 30 feet of surface	230-237	7
Very hard white limestone	237-287	50
Soft gray limestone	287-315	28
Hard grayish and brownish limestone, fossiliferous at 328 to 350 and 398 to 410 feet: sulphur water at last depth.	315-410	95
Hard grayish and brownish cherty limestene: water stands within 26 feet of surface at 450 feet	410-450	40
Very soft gray limestone	450-470	20
Hard grayish and brownish limestone: water stands within 22 feet of surface at 505 ft	470-505	35
Soft gray limestone	505-513	8
Soft and very soft grayish limestone: hard stratum at 630 to 650 feet	513-735	222
Hard gray limestone: water stands within 14 feet of surface	735-825	90
Clinton:[2]		
Very soft dark-red ferruginous shale	825-880	55
Maquoketa (or Cincinnati) shale:		
Very soft gray limy shale	880-986	106
Total depth		986

[1] Bulletin 298. U. S. Geol. Survey, p. 295.
[2] The Clinton is described by F. T. Thwaites as iron ore.

Another possible interpretation is to place the 105 feet of brownish and grayish limestone associated with the sandy limestone and gray shale, depth 90 to 195 feet, with the Milwaukee (Hamilton) shale formation of the Devonian, as the latter is known to overlie the Niagara at various places farther south along the lake shore in Ozaukee and Milwaukee counties. According to this interpretation the complete thickness of the Niagara at this place would be 630 feet.

The Niagara formation is of variable thickness on account of erosion. The thickness at Chilton in Calumet county under 28 feet of drift is 170 feet, and at Two Rivers, under 92 feet of drift, 280 feet, and near Manitowoc under 90 feet of drift at least 630 feet. The minimum thickness in the county is probably not less than 150 feet, and the maximum thickness of the ridges may reach over 600 feet.

The second city well of Two Rivers shows a thickness of 670 feet of Niagara.

The approximate thickness of the formations in Manitowoc county from the surface down to the Pre-Cambrian granite based on the logs of various deep wells may be summarized as follows:—

Approximate thickness of formations in Manitowoc County.

Formation.	Thickness.
	Feet.
Surface deposits	0 to 200
Devonian shale (probably present)	0 to 150
Niagara limestone	150 to 650
Cincinnati shale	280 to 300
Galena—Platteville (Trenton) limestone	200 to 250
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	600 to 650
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the glacial drift and the Niagara limestone. In a few very deep wells the formations underlying the Niagara are drawn upon. The glacial drift consists of clay, sand, gravel and boulders indiscriminately mixed to form the glacial till which was deposited directly by the ice, and distinct beds of sand and gravel interstratified with clay which were deposited by water associated with the ice. It is in the beds and seams of clear sand and gravel that water in the drift is found in abundance, at depths relatively near the surface. The wells in the drift are generally quite variable in depth, being deeper on the uplands than on the lower slopes of the valleys. Open dug wells are usually shallow, but drilled wells in order to obtain a good supply generally reach about 100 feet on the uplands, obtaining their supply in gravel beds near the underlying rock, or from a short distance into the rock.

The wells in the Niagara limestone obtain an abundant supply of good clear water from the numerous fractures and open fissures that permeate this formation. Wells in the limestone are drilled to variable depths depending on their location on the uplands or in the valleys. The water level is near the surface in the valleys and on the uplands is usually less than 100 feet below the surface.

FLOWING WELLS

Flowing wells are common over various parts of Manitowoc county in both the surface deposits and in the underlying Niagara limestone.

The flowing wells in the drift have their source of supply in gravel beds underlying clay and between beds of clay on the slopes of the uplands and in the valley bottoms. There are a number of flowing wells in the city of Two Rivers, from 75 to 100 feet deep, in gravel or the underlying limestone, the head being 4 to 20 feet above ground.

In the village of Cleveland is a flowing well 23 feet deep owned by J. Hill. This well passed through 18 feet of clay and 5 feet of gravel hardpan. The water was struck in the gravel and rises 4 feet above the surface, but ceases to flow during the dry season.

Northeast of Cleveland near the Lake in Secs. 14 and 15, T. 17 N., R. 23E., Centerville, are four copious flows which spring from the gravels overlying the rock. The depth of wells is greater than that of the Pigeon Valley wells, averaging about 130 feet. The wells have high pressure and strong flows. There are other good wells in this vicinity and in the town of Mosel to the south, which draw their water from the Niagara limestone. In the town of Two Creeks, on the lake shore, about half way between Manitowoc and Kewaunee are four flowing wells about 80 feet deep. Three of these wells owe their flow to a water bearing bed of gravel just above the rock, while the fourth is fed from crevices a few feet within the Niagara limestone.

The surface of the Niagara limestone at the city of Manitowoc as elsewhere along the eastern part of the county, is thickly covered with impervious drift and lacustrine clays, and the rock strata beneath rise to the westward and readily transmit the water from the uplands, so that the requisite conditions for flowing wells are found in many places on the slope at no great distance within the limestone. The flowing well of J. Haltz, 203 feet deep, and that of the Manitowoc Malting Co., 110 feet deep in Manitowoc, are of this type, the artesian heads being 24 and 3 feet respectively above the surface.

The water in the deep seated strata of St. Peter and Potsdam sandstone is very probably not under sufficient pressure along the lake shore north of Manitowoc to develop a head above the level of the lake. The deep city well in Two Rivers drilled to the pre-Cambrian granite, at depth of 1,800 feet, failed to obtain a flow from the deep sandstone horizons, though a small flow was obtained from the Niagara limestone at depth of 230 feet. No other wells are known to reach the sandstone in this county. The explanation for the absence of artesian flows from the sandstone, north of Manitowoc, is given on pp. 80–1.

SPRINGS

Springs are a common source of water supply along the lower slopes of the hills, especially near the contact of the drift and the underlying rock, or directly from the rock. The fact that the water in many places on the lower slopes is held under pressure develops conditions favorable for springs. The Maribel Mineral Spring near Manitowoc furnishes a large supply of mineral water for the trade.

WATER SUPPLIES FOR CITIES AND VILLAGES

Manitowoc.—Manitowoc, situated on Lake Michigan, at the mouth of the Manitowoc river, has a population of 13,027. The city water supply is obtained from two large wells, 25 feet in diameter, and 20 feet deep on the shore of the lake. The well water is obtained from layers of gravel between red clay. An auxiliary supply is obtained from two intakes extending into the river at depth of 5 feet. The average daily pumpage is 1,200,000 gallons. The sewage, without purification, empties into the river near its mouth. About 60 per cent of the houses are connected with the water and sewage systems. Continuous pumping for a few hours will exhaust the well supply.

There are many private wells in the city from 20 to 60 feet deep in drift. There are also a number of deeper wells that penetrate some distance into the Niagara limestone. The two best wells furnish about 200,000 gallons in 24 hours each. William Rahr's well, 210 feet deep, when heavily pumped, yields as much as 500 gallons per minute. No measurements as to lowering of water have been taken, but it has been noted that these wells affect others on higher ground. William Rahr's well and the Manitowoc Glue Company's well interfere with each other as shown by test, but as they are both on the same level and heavily pumped one well does not take the water at the expense of the other. The water for the most part comes from the Niagara limestone and some of it is too hard for boiler use. (See table of analyses, No. 3 and No. 4.) The logs of other wells at Manitowoc, many of which are flowing, are on file in the office of the State Survey.

Two Rivers.—This city located on Lake Michigan, at the mouth of Twin river, has a population of 4,850. The city water supply is obtained from 3 large open wells on the bank of the lake into which the water filters from the lake. The sewerage empties into the Twin river. About 45 per cent of the houses have water and sewer connections. The average daily pumpage is 108,000 gallons.

Many of the private wells in the city are from 20 to 40 feet in the

gravel and sand. There are also a number of flowing wells in the gravel and underlying limestone, from 75 to 100 feet deep. These wells flow from 4 to 20 feet above the ground.

The deep city well was drilled in 1898 by F. M. Gray of Milwaukee. At a depth of 230 feet in the limestone a flow was struck that yielded one-fourth inch stream but the water from the deeper horizons failed to flow. Mr. Dunn, who helped drill the well, reports the following section:

Section of Two Rivers City Well.

Formation.	Thickness.
	Feet.
Sand and clay (Pleistocene)	92
Limestone (Niagara)	280
Slate or shale (Cincinnati)	300
Limestone (Galena Trenton)	250
Sand rock (St. Peter, Lower Magnesian)	250
Alternating sandstone and limestone (Potsdam)	628
Granite (Pre-Cambrian)	60
Total depth	1860

Another well was drilled by the city in 1914 to depth of 1,640 feet, striking, however, highly mineralized water, as indicated on the following page. This well passed through a much greater thickness of the Niagara limestone than the former city well, as is shown in the following log:

Log of well at City Water Works, Two Rivers, Wis.

Drilled by W. H. Gray Bros., 1914.
Samples sent by Geo. H. Wehausen.
Samples examined by F. T. Thwaites, Jan., 1915.

Formation.	Depth.	Thickness.
Glacial drift and lake deposit:		
Sand	0- 15	
Hardpan	15- 17	
Quicksand	17- 82	
Dry red clay	82- 100	100
Niagara limestone:		
Hard gray dolomite with chert towards bottom	100- 560	
Darker gray shaly dolomite	560- 620	
Gray to yellowish cherty dolomite	620- 770	670
Cincinnati shale:		
Grayish-blue shaly dolomite and dolomite shale	770- 950	
Bluish gray clay shale	950-1100	330
Galena-Trenton limestone:		
Grayish-blue to brownish dolomite	1100-1295	195
St. Peter:		
Fine to medium grained grayish ferruginous sandstone	1295-1340	
Reddish yellow fine sandstone, to yellowish gray and light reddish in some layers	1340-1595	300
Lower Magnesian:		
Dark reddish sandy dolomite shale	1595-1610	15
Potsdam:		
Gray and yellowish brown medium sandstone	1610-1640	30

The second city well is located 1,750 feet east of the first well, the curb is 6 feet above Lake Michigan, and the head of water is level with the lake.

Kiel.—Kiel, population 1,244, recently installed a public water supply system, the supply being obtained from one well 29 feet deep. About 40 per cent of the population utilizes the system. The average daily pumpage is about 50,000 gallons.

The log of the city well in Kiel, drilled in 1905, which did not furnish sufficient water for a city supply, is as follows:

Log of city well of Kiel.

Formation.	Thickness.
	Feet.
Surface (no record)	150
Niagara limestone	304
Cincinnati shale	17
Total depth	471

A sufficient artesian water supply could very probably have been obtained if the well had been drilled to a depth of about 1,200 feet and drawn its supply from the underlying St. Peter sandstone.

QUALITY OF THE WATER

The available mineral analyses of water supplies of Manitowoc county are shown in the following table. The water obtained from springs, and from the wells in the surface deposits and the Niagara limestone, is usually of moderate mineral content. Some of the waters, however, obtained from the Niagara, even in relatively shallow wells, as illustrated by No. 5 and No. 6 in Manitowoc, are very high in mineral content and contain large amounts of calcium sulphate, gypsum, in solution. The amount of chlorides is relatively small as compared with the sulphates.

The water from the well recently drilled by the city of Two Rivers in 1914, to depth of 1,640 feet, is high in calcium and sulphate, and is much like the highly mineralized water from the wells in the Niagara in Manitowoc. The analyses of two samples of this water made by Hantke's Brewer's Laboratory, of Milwaukee, Sample No. 1, taken

after plugging well at 800 feet, date of analysis Nov. 25th, 1914, and sample No. 2, taken at 1,640 foot level, date of analysis Dec. 4, 1914, is as follows:

Analyses of water of Two Rivers city well.

(Analyses stated as salts in parts per million)

	No. 1	No. 2
Silica (SiO_2)	70.8	20.0
Aluminum and iron oxides (Al_2O_3 Fe_2O_3)	92.5	trace
Calcium sulphate	1,860.0	2,307.1
Magnesium sulphate	835.0	200.4
Magnesium carbonate	....	161.2
Magnesium dhloride	....	154.5
Sodium chloride	169.6	405.0
Sodium sulphate	519.7	....
Total	3,547.6	3,257.2

The Manitowoc city well water, No. 4, contains 1.73 pounds of incrusting solids in 1,000 gallons, and the artesian well water at Cleveland, No. 7, contains 3.67 pounds in 1,000 gallons.

Mineral analyses of water in Manitowoc County.

(Analyses in parts per million.)

	Rivers.		Spring.	Surface deposits.	Niagara limestone.			
	1.	2.	3.	4.	5.	6.	7.	8.
Depth of well	....	....	....	20	110	150	219	472
Silica (SiO_2)				7.8			20.0	
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	undt.	2.6	14.0	0.8	10.6	20.	0.8	undt.
Aluminium oxide (Al_2O_3)	....	....	2.1	....	1.7	....	....	....
Iron (Fe)	....	....	1.4	....	0.6	....	....	....
Calcium (Ca)	46.6	42.8	46.1	47.2	570.9	602.6	78.8	50.8
Magnesium (Mg)	24.9	26 7	27.0	20.6	99.8	165.	49.7	35.9
Sodium (Na)	3 2	8.6	4 6	17.5	62.9	205.7	13.1	10.7
Potassium (K)			2.2		11.6	5.8		
Carbonate radicle (CO_3)	107.2	138.2	141.5	106.8	142.6	259.	157.4	164.3
Sulphate radicle (SO_4)	45.2	2.3	2.9	25.1	1538.7	1790.	144.8	12.5
Chlorine (Cl)	....	1.5	7.0	26.9	105.5	196.	12.1	7.2
Total dissolved solids	227.	228.	249.	252.	2544.	3244.	477.	281.

1. Sheboygan River, Kiel. Analyst, G. N. Prentiss, April 8, 1901.
2. Sheboygan River, Kiel. Analyst, Chemist C. M. & St. P. Ry. Co., July 8, 1891.
3. Maribel Springs, Maribel. Analyst, W. W. Daniells
4. Well of City Water Works, Manitowoc, Analyst, G. M. Davidson, Oct. 19, 1907.
5. Well of Manitowoc Malting Co., Manitowoc, Analyst, E. G. Smith.
6. Well of Rahr & Sons, Manitowoc, Analyst, G. Bode, Geol. of Wis. vol. 2, p. 31, 1877.
7. Artesian flowing well, Cleveland, 800 feet north of station. Analyst, G. M. Davidson, May 2, 1907.
8. City well, Kiel. Analyst, G. N. Prentiss, Sept. 21, 1905.

Marathon County

Marathon County, located in the north central part of the state, the largest county in the state, has an area of 1,532 square miles, and a population of 55,054. About 53.6 per cent of the county is laid out in farms, of which 34.6 per cent is under cultivation.

SURFACE FEATURES

Marathon County[1] is a dissected upland plain, the uplands generally ranging from 1,300 feet in the southern part to 1,500 feet in

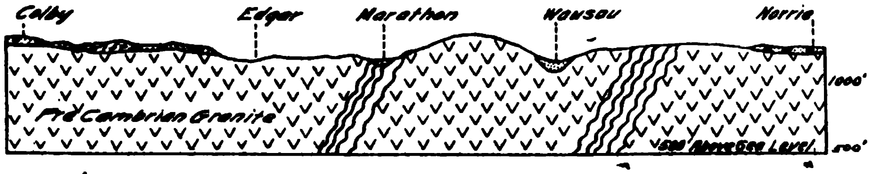

Fig. 47.—Geologic section, east-west, across Marathon County.

the northern part, with the valley bottoms and slopes lying from 200 to 300 feet below these altitudes. The quartzite hills below referred to extend above the general level of the upland plain, Rib Hill reaching an altitude of 1,942 feet. The soils are generally loams, with sandy soils along the Wisconsin river.

GEOLOGICAL FORMATIONS

The geological formation is principally the Pre-Cambrian granite. In a few places only, namely in the southeastern and in the western parts of the county, occur small outcrops of the overlying Upper Cambrian (Potsdam) sandstone. Glacial drift is abundant in the eastern, northern and western parts of the county. The alluvial formation of sand and gravel has a considerable width along the Wisconsin river in the southern part of the county. Rib Hill, Mosinee Hills and Hardwood Ridge, southwest of Wausau, are prominent topographic features. The cross section, Fig. 47, illustrates the geological structure.

The thickness of the glacial drift is variable and probably reaches a maximum of 150 to 200 feet in some of the morainic ridges. The al-

[1] For topography of Marathon County see the Wausau and the Marathon special maps published by the U. S. Geological Survey, Washington, D. C.

luvial filling of sand and gravel in the valleys is known to be over 130 feet at Wausau, and may reach 150 to 200 feet in the deepest parts of the old channels. The Potsdam sandstone occurs in only a few localities, and nowhere exceeds a thickness of 50 feet. The approximate range in thickness of the formations overlying the Pre-Cambrian granitic formations may be summarized as follows:

Approximate range in thickness of formations in Marathon County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 200
Upper Cambrian (Potsdam) sandstone (present in only a few localities)	0 to 50
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The source of the groundwater supplies is in the crystalline rock, the glacial drift, and the alluvial sand and gravel. Only a limited supply is derived from the cracks and fissures of the crystalline formations, but this is quite generally sufficient for domestic purposes on the farms and in the small villages. The glacial drift is relatively abundant in the eastern, northern and western parts of the county, and generally a sufficient supply for domestic purposes is obtained in the drift or at the contact of the drift and underlying granite, where the drift is 20 feet or more in thickness. The sandy alluvial formations are an important source of the supply for those cities located along the Wisconsin river and tributaries. As most of the cities like Wausau are located on rivers on the sites of water powers, the alluvial sand and gravel formation is an important source of water supply. Figures 48 and 49 illustrate the geological relations of the alluvial formations to the Pre-Cambrian granite at Wausau and Mosinee. The Potsdam sandstone, which is an important source of water supply in Clark County, is drawn upon in only a few farm wells on the western margin of Marathon County.

WATER SUPPLIES FOR CITIES AND VILLAGES

Wausau.—Wausau, with a population of 16,560, is located on alluvial terraces of the Wisconsin river, at the site of extensive water power. Most of the city lies on the valley bottom, but a portion lies on the slopes of the valley carved out of the crystalline uplands.

Most of the private wells in the city, either dug or driven, range in depth from 20 to 60 feet, depending upon their location and elevation with respect to the level of the river. Prior to 1907 the city supply of water was derived from a well located 150 feet from the Wisconsin river, which was 35 feet deep and 40 feet in diameter, and had connected with it a 24-inch vitrified pipe, 180 feet long, laid parallel to the river, and 20 feet below the surface of the ground. The water contained a large quantity of iron in solution, which supported a copious growth of *crenothrix*, the growth of which seriously clogged the city mains. In some instances the small pipes, 1½ to 2 inches in diameter, were entirely filled. It became imperative, therefore, that either the

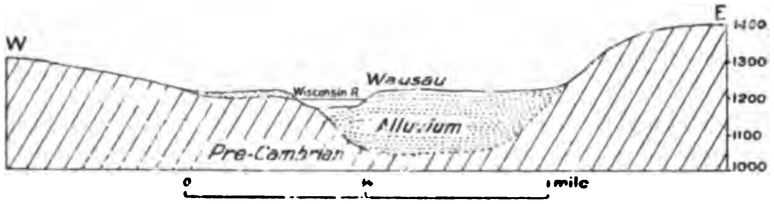

Fig. 48.—Geologic secton at Wausau showing relations of the alluvial sand and gravel to the Pre-Cambrian granite.

objectionable effect of the iron in the water would have to be remedied or a new supply of water obtained. Fortunately in this case, a good supply of water essentially free from iron was readily obtained in the deeper strata of alluvial sand and gravel.

The old supply of water was therefore cut off and the new supply from a system of 40 six-inch wells, 135 feet deep, was connected up to the city mains in 1907. The new supply of water is derived from wells located east of the old open well, which is now used as a storage reservoir. We are indebted to Mr. C. A. Nutter, City Engineer, for maps and data regarding the present supply.

One of the wells struck granite at 134 feet, but the others did not reach the granite at this depth. It is likely that the old valley, now filled with the alluvial gravel, extends to a maximum depth of nearly 200 feet at Wausau.

The character of the formation, essentially uniform in all the wells, is as follows:

Section of Wausau city wells.

Formation.	Thickness.
	Feet.
Coarse gravel and sand	20
Finer gravel and sand	55
Stratum of hard pan	1
Fine gravel and sand	44
Very large coarse gravel, some sand	14
Total depth	134

The chemical composition of the old supply of water showed an average of 0.7 to 0.8 parts per million of iron in solution; the new supply contains from 0.05 to a small trace per million, and the chemists comment upon the extreme purity and softness of the new supply of water.

The temperature of the old supply was 49°. The lower temperature of the new supply is the only bad feature. It is reported that the new supply is rapidly clearing out the pipe system.

The available supply from the new system is estimated at 6,000,000 gallons at the normal water stage. The average daily pumpage in 1913 was 2,650,000 gallons. About 85 per cent of the people use the water supply and sewage system. The water works is connected with an intake extending into the river. No cess pools are allowed where sewer connections are possible. The sewage, without treatment, is emptied into the Wisconsin river.

Edgar. —The population of Edgar is 746. The wells in Edgar strike granite at depths of 10 or 15 feet. Although no marked difficulty is experienced in obtaining sufficient supplies for domestic or general farm purposes, the supply is not sufficient for large quantities. The C. & N. W. R. R. has two wells here, neither of which supply a sufficient amount of water for the locomotives. The swampy ground to the west shows many small springs, and offers a possibility of finding a much greater underground supply. It has not, however, been investigated.

The deepest well, at C. Du Longs, is as follows:

Log of Du Long's Well, Edgar.

Formation.	Thickness.
	Feet.
Soil and drift	8
Granite, disintegrated (meager supply)	12
Granite hard (water from fissures)	61
Total depth	81

Marathon City.—Marathon City, population 656, is located on granite rock, on the south side of the Rib river. The wells are generally relatively shallow, from 10 to 40 feet deep, drawing the supply from fissures in the granite. It is probable that any large supply of water for this city would have to be derived, either from the Rib river or from the alluvial gravel and sand on the north side of the river.

Mosinee.—Mosinee, like Wausau, is located upon the terrace of the Wisconsin river, at the site of an extensive water power. An abundant water supply for domestic purposes can be obtained at depths of 15 to 40 feet in the alluvial sand and gravel, depending upon the elevation above the river. An abundant supply, for public uses, could be obtained here and elsewhere along the Wisconsin river, like that recently developed at Wausau. See Fig. 49. A city supply was recently installed, being obtained from a well 15 feet deep.

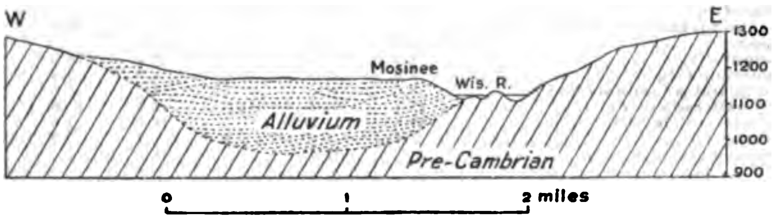

Fig. 49.—Geologic section at Mosinee showing the alluvial sand and gravel overlying the Pre-Cambrian granite.

Athens.—The village of Athens, population 904, is located on the crystalline rock on Black Creek. There is a covering of a variable amount of drift over the crystalline formations, so that many wells derive their supply at the contact of the drift and the underlying granite. The wells are generally from 15 to 40 feet deep. Any large supply of water probably, such as would be required for a public system, would have to be derived from the surface formation in the valley northwest of the village.

QUALITY OF THE WATER

The mineral analyses of water of Marathon county, are shown in the following table. The surface water of creeks, as well as that obtained from shallow wells in the surface deposits varies from very soft to hard water. It is very likely that the waters analyzed are typical for the entire county, and that fairly soft water generally occurs in all the geological formations. All the waters are carbonate waters with calcium as the predominating constituent, and the alkalies mainly so-

dium, relatively important. The organic matter in the city water supply of Wausau indicates a contaminated water supply at the time the sample was collected, probably on account of water obtained either directly or indirectly from the river.

The city water of Wausau, No. 4, contains 0.65 pounds of incrusting solids in 1,000 gallons, the water from Scott creek at Marathon city, No. 1, contains 0.41 pounds in 1,000 gallons, and that from the creek at Stratford, No. 2, contains 1.39 pounds in 1,000 gallons.

Mineral Analyses of water in Marathon County.

(Anaylses in parts per million.)

	Creeks.		Surface deposits.			
	1.	2.	3.	4.	5	6.
Depth of well....feet..	....	....	37	154	....	35
Silica (SiO_2)....	10.4	10.9	20.9	14.3	....	9.2
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)....	8.7	5 1	2 0	Trace	14.7	Trace
Calcium (Ca)....	9.3	55.2	54.	16 4	18.0	12.6
Magnesium (Mg)....	1.3	11.8	16.6	4 9	5.4	2.6
Sodium and potassium (Na+K)....	8.0	11.5	5.1	4.2	7.5	9.6
Carbonate radicle (CO_3)....	13 8	104.1	116.3	28.9	8.08	34.6
Sulphate radicle (SO_4)....	19.8	18.8	9.4	18 0	2.5	2 3
Chlorine (Cl)....	2.4	1.6	7.8	2.7	2.2	1.7
Organic matter....	....	32.7	....	13.8	....	....
Total dissolved solids....	74.	218.	233.	89	131.	73.

	Surface deposits.					
	7.	8.	9.	10.	11.	12.
Depth of well....feet..	River	30	23	23	20	24
Silica (SiO_2)....	....	3.9	1.5	....	1.7	Undt.
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)....	3.6			Trac		
Calcium (Ca)....	15.2	17.5	14.5	11.4	6 0	21 8
Magnesium (Mg)....	4 8	....	3.6	3.5	2 0	6.4
Sodium and potassium (Na+K)....	6.9	4 5	12 6	12.1	5 0	21.0
Carbonate radicle (CO_3)....	40.5	22.1	35.0	29 4	14.1	23.2
Sulphate radicle (SO_4)....	3.0	6.7	12.5	12.8	4.2	84.0
Chlorine (Cl)....	1.4	7.0	5 1	4.5	4 6	....
Total dissolved solids....	75.	62.	85.	74.	38.	156.

1. Scott Creek, 2¼ miles W. of Marathon City, Analyst, G. M. Davidson, Nov. 15, 1904.
2. Creek at Stratford, Analyst, G. M. Davidson, Sept 27, 1909.
3. Well of C. & N. W. Ry. Co., Edgar, Analyst, G. M. Davidson, Feb. 19, 1895.
4. City Water Supply, Wausau, Analyst, G. M. Davidson, July 13, 1909.
5. City Water Supply, Wausau, Analyst, E. G. Smith.
6. Well of City Water Supply, Wausau, Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 4, 1892.
7. Well of City Water Supply, Wausau, Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 7, 1896.
8. Private well, Wausau, Analyst, Chemist, C. M. & St. P. Ry. Co, July 26th, 1886.
9. Well of the C. M. & St. P. Ry. Co., Mosinee, Analyst, Chemist C. M. & St. P. Ry. Co., Oct. 22, 1896.
10. Well of C. M. & St. P. Ry. Co., Mosinee, Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 18, 1892.
11. Well of C. M. & St. P. Ry. Co., Dancy, Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 15, 1897.
12. Well of C. M. & St. P. Ry. Co., Dancy, Analyst, Chemist, C. M. & St. P. Ry. Co., April 13, 1900.

Marinette County.

Marinette County, located in the northeastern part of the state on Green Bay, has an area of 1,396 square miles and a population of 33,812. Only 24.2 per cent of the county is laid out in farms, of which 36.2 per cent is under cultivation. Most of the improved farm land lies in the southeastern part, adjacent to Green Bay.

SURFACE FEATURES

The surface of Marinette county is a gently undulating plain sloping down to the southeast. The Menominee river and tributaries and the Peshtigo river are the drainage lines. Thunder Mountain and Silver Cliffs are prominent quartzite hills in the western part of the county. Along the shore of Green Bay, between Marinette and Peshtigo, is a broad low tract of land from 10 to 20 feet above the level of Green Bay. The northwestern part of the county has a somewhat steeper slope to the southeast than the northeastern part. The altitude of the low land along Green Bay is only slightly above 580 feet, the level of the bay. The general altitude of the upland plain in the northwestern part of the county is between 1,200 and 1,600 feet. The Peshtigo river flowing southeast down this slope is characterized by a series of rapids 10 to 40 feet in height, falling about 550 feet from Taylors Falls to the Lower Sandstone rapids, a distance of 43 miles. From the Lower Sandstone rapids to the mouth, a distance of 50 miles, the fall is only about 100 feet.

GEOLOGICAL FORMATIONS

In the northwestern half of the county the formations are granite and other crystalline rocks; in the southeastern half are the overlying Upper Cambrian (Potsdam) sandstone, Lower Magnesian limestone, St. Peter sandstone and the Galena-Platteville (Trenton) limestone formations. The bedrock formations are quite generally covered with glacial drift and alluvial deposits.

The soils in the northern part are generally sandy, while those in the southern part are generally loams with the exception of a broad sandy and marshy tract between Peshtigo and Marinette. The geological structure is illustrated in Fig 50.

The thickness of the surface formation is quite variable on account of the irregularity in the surface of the rock on which it was deposited. The drift attains its greatest thickness in the belt of hummocky drift hills in the northern part of the county. The alluvial sand and gravel attains its greatest thickness in the pre-glacial valleys, which extend across the county.

The thickness of the stratified rocks is also quite variable on account of the extensive erosion of the formations. The complete thickness of the formations is preserved only where they are protected from erosion by the overlying strata, as indicated in the cross section. The thickness of the Upper Cambrian (Potsdam) is somewhat variable on

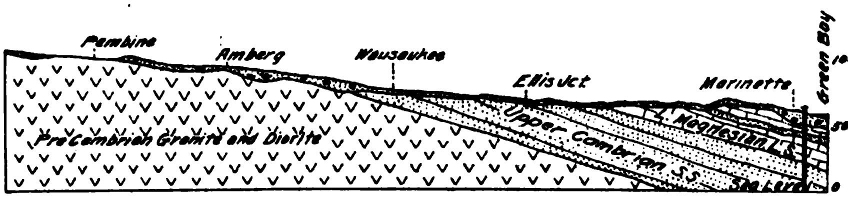

Fig. 50.—Geologic section, north-south, across Marinette County.

account of the uneven surface of the Pre-Cambrian floor upon which it was deposited. The uneven floor of the Pre-Cambrian is illustrated by the occurrence of the mounds of quartzite at Thunder Mountain and Silver Cliff, which project several hundred feet above the general plain-like surface of the surrounding Pre-Cambrian. In the city of Marinette the deep artesian wells evidently strike a buried mound of hard granite or quartzite, which stands about 200 feet above the general level of the surrounding buried Pre-Cambrian at Oakwood Beach. As in many other localities, the thickness of the St. Peter sandstone and Lower Magnesian formations is difficult to determine in the records of deep wells. In most of the deep wells in the city of Marinette, a considerable thickness of Lower Magnesian limestone is reported, and very little or no St. Peter sandstone. However, in a few of the wells the Lower Magnesian limestone strata are instratified with beds of sandstone a few feet thick, and in the well drilled for oil and gas, two miles south of the I. Stephenson well, samples preserved by Mr. H. B. Simcox, shows the St. Peter sandstone well marked at depth of 325 to 400 feet.

The section of the Marinette city well, as interpreted by Dr. W. C. Alden, is as follows:

Log of Marinette City Well.

Formation.	Depth.	Thickness.
Pleistocene	Feet.	Feet.
Red sand and gravel	1-70	
	70-85	85
Galena limestone		
Round chipped limestone	85-144	59
Trenton limestone		
Blue shale	144-196	
Chipping limestone coarse	196-240	
Chipping limestone	240-250	
"Slate" light blue and white	250-320	176
(Base of Trenton uncertain. St. Peter sandstone absent.)		
Lower Magnesian limestone		
Chipping limestone coarse	320-450	
Coarse chipping limestone light colored, and dolomite	450-550	230
Upper Cambrian (Potsdam) group		
White sandstone, very white, mealy looking	550-560	
White sandstone	560-560	
White and greenish, calceraous sandstone	560-670	
White sand	670-685	
Rounded white sand	687-712	162
Huronian or Archean		
"Granite" (broken and lost)	712-716	4
Dark red quartzite	716-	
Total depth		716

The following record of the Oakwood Beach well is very similar to the above, the principal difference being the greater thickness of the Potsdam formation in the Oakwood well. In the Oakwood Beach well a continuous thickness of 334 feet of limestone was penetrated below the surface deposits, and assuming approximately the same depth for the base of the Trenton as assumed by Dr. Alden in the city well, this thickness of limestone is divided between the Trenton and Lower Magnesian, as interpreted in the following record.

Log of Oakwood Beach Well.

Formation.	Thickness.
	Feet.
Glacial and alluvial.	
Sand and gravel	90
Clay	21
Galena—Platteville (Trenton).	
Limestone, about	214
St. Peter sandstone (absent).	
Lower Magnesian.	
Limestone, about	120
Sandstone	25
Red marl	15
Gray limestone	25
Upper Cambrian (Potsdam).	
Colored sandstone	357
White sandstone	57
Pre-Cambrian granite at bottom	
Total depth	917

The approximate range in thickness of the formations in the county may be summarized as follows:

Approximate thickness of formations in Marinette County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena—Platteville (Trenton) limestone	0 to 250
St. Peter and Lower Magnesian	0 to 250
Upper Cambrian (Potsdam) sandstone	0 to 500
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing formations in the southeastern part of the county are the Potsdam sandstone, the St. Peter sandstone and the Lower Magnesian and Trenton limestone formations, and the surface formation of drift and alluvial sand. In the northwestern part the surface deposits of drift and stratified sands are the most important sources of supply, the granite furnishing only small amounts.

The general water level is usually only 10 to 40 feet below the surface over most of the county. The wells in the rural districts of the county are of variable depth, depending upon whether their location is on the upland slopes, in the valleys, or on the level plains. Very few wells are more than 100 feet deep, and most of them are only from 15 to 40 feet in depth. Within the area of the level sandy tract in the town of Peshtigo the water level is generally from 5 to 15 feet below the surface, and open wells are generally only from 10 to 20 feet deep. By the use of driven pipes better water, less liable to contamination, could be obtained from greater depths, from depth of 20 to 30 feet. In the town of Grover most of the farm wells obtain sufficient water in the drift overlying the limestone at depths of 15 to 30 feet.

Most of the drilled wells are deeper than the open dug wells and pentrate the limestone to a variable depth sometimes reaching 100 to 150 feet. In the towns of Pound and Beaver the wells are generally from 20 to 30 feet deep in the low and level tracts and somewhat deeper on the higher lands.

FLOWING WELLS

Flowing artesian wells occur along the shore of Green Bay deriving their flow from the sandstone strata, either the St. Peter or the Pots-

dam underlying the impervious Galena-Platteville (Trenton) limestone. The flowing wells in the city of Marinette draw their supply from the Lower Magnesian formation and the Potsdam sandstone, the head of the water being 20 to 25 feet above the surface, or from 30 to 35 feet above the level of the bay.

At County Line on the boundary of Marinette and Oconto counties is an artesian well 210 feet deep, which flowed when first drilled about 14 feet above the surface. The elevation of the curb is estimated to be about 30 feet above Green Bay. This well was drilled in 1904, and is cased only 25 or 30 feet and has lost considerable pressure. At this place the Trenton limestone was reached at depth of 10 feet, and the underlying sandstone, the St. Peter, from which the flow is obtained was reached at 190 to 200 feet.

Flowing wells with head ranging from 30 to 50 feet above the level of Green Bay should be possible in the southeastern part of Marinette county. The head at the Oakwood Beach well in Marinette is about 35 feet above the level of Green Bay and at County Line, 3 miles from the bay, about 40 to 45 feet, the head gradually rising as the distance from the shore increases. In the village of Peshtigo wells apparently have not been drilled through the Trenton limestone, the deepest wells being only 120 feet deep. The elevation of Peshtigo is only 20 or 30 feet above Green Bay and artesian flows should be obtainable from wells that penetrate the Trenton to the underlying water-bearing sandstone in the vicinity of Peshtigo.

WATER SUPPLIES FOR CITIES AND VILLAGES

Marinette.—This city, population 14,610, is located on the Menominee river, where it enters into Green Bay. The city water supply is mainly taken from Green Bay, one-half mile northeast of the old Pemberthy dock, at a depth of 22 feet. A part of the supply is also reported to be taken from the Menominee river, and a part from an artesian well, 765 feet deep. The average daily pumpage is 1,355,000 gallons. The sewage is filtered by the Jewel system of filters and emptied into the Menominee river. About 95 per cent of the houses are reported to have water and sewer connections.

Many private wells in Marinette are from 15 to 25 feet deep in sand. There are several deep artesian flowing wells of interest in the city, already cited. Some of these wells are from 700 to 917 feet deep, reaching through the Potsdam sandstone. The section of the Oakwood Beach well, altitude of curb 591 feet, depth 917 feet to granite, and flowing 23 feet above the surface is given above.

Peshtigo.—The city of Peshtigo, population 1,975, has no public water supply system. There are from 25 to 35 private wells in the city, four to five inches in diameter, having depths of 40 to 120 feet, striking the Trenton limestone rock at a depth of about 25 feet below the surface. The general water level in Peshtigo is from 10 to 20 feet below the surface, and it is probable that many open wells are only from 15 to 25 feet deep. Conditions appear to be favorable in Peshtigo for obtaining artesian flows in wells that penetrate the Trenton limestone and reach into the underlying sandstone. A partial sewage system is installed along the main streets, the sewage being emptied into the Peshtigo river below the city.

Wausaukee.—The water supply of the village of Wausaukee is obtained from private wells from 30 to 40 feet deep in gravel and sand. In the western part of the village, on the uplands, are some wells 125 to 150 feet deep, which reach the sandstone at 60 to 70 feet.

In Coleman and Pound the wells are generally from 20 to 40 feet deep in sand and drift. In Amberg the wells vary in depth, on account of the proximity of granite, but are generally from 20 to 40 feet deep in sand and gravel. In Pembine, wells are generally from 25 to 30 feet deep in sand and gravel. In the southeastern part of Dunbar, some of the wells reach an impervious clay bed before striking water. Considerable difficulty has been encountered in obtaining a sufficient supply from the clay or the underlying hard granite at Dunbar.

QUALITY OF THE WATER

The analyses of the water from different parts of Marinette county are shown in the following table. The waters from the surface deposits are hard waters of moderate mineral content, while that obtained from the Stephenson artesian well, mainly from the Upper Cambrian (Potsdam) sandstone, is a very hard water high in mineral content. In the Stephenson well, No. 6, the sulphates greatly predominate over the carbonates and the chlorides, a characteristic of the deep artesian water across the river in Menominee, Mich. Waters from the surface deposits are all calcium carbonate waters.

The water from the railroad well in Marinette, No. 2, contains only 1.26 pounds of incrusting solids in 1,000 gallons, while the highly mineralized water from the Stephenson artesian well, No. 11, contains 9.11 pounds in 1,000 gallons.

Mineral analyses of water in Marinette County.

(Analyses in parts per million.)

	River.	Surface formation.				
	1.	2.	3.	4.	5.	6.
Depth of well.................feet..	....	9	14	20	20	24
Silica (SiO_2)... Aluminum and iron oxides (Al_2O_3+Fe_2O_3)...	3.6	20.2	4.9	3.9	undt.	7.6
Calcium (Ca)...	15.2	38.4	55.6	60.9	66.5	32.3
Magnesium (Mg)...	4.8	9.8	21.4	23.5	24.8	11.6
Sodium (Na)... Potassium (K)...	6.9	6.1	8.7	9.9	8.7	8.1
Carbonate radicle (CO_3)...	40.5	72.1	136.4	148.5	159.9	75.6
Sulphate radicle (SO_4)...	3.0	10.	13.6	12.3	7.5	8.7
Chlorine (Cl)...	1.4	9.3	3.4	7.4	....	8.2
Organic matter...	....	15.9	....	....	....	....
Total dissolved solids...	75.	166.	244.	266.	262.	152.

	Surface formation.				Upper Cambrian sandstone.
	7.	8.	9.	10.	11.
Depth of well.................feet..	22	60	25	48	716
Silica (SiO_2)... Aluminium and iron oxides (Al_2O_3+Fe_2O_3)...	undt.	5.3	5.1	undt.	5.1
Aluminium oxide (Al_2O_3)...	....	....	....	....	29.4
Iron (Fe)...	....	....	....	....	2.9
Calcium (Ca)...	55.4	80.1	70.5	68.1	213.9
Magnesium (Mg)...	26.0	27.0	24.7	34.5	63.1
Sodium (Na)...	4.8	26.7	7.9	6.7	51.4
Potassium (K)...	....	....	....	....	9.0
Carbonate radicle (CO_3)...	126.2	186.4	167.2	158.3	25.7
Sulphate radicle (SO_4)...	28.0	7.5	8.2	7.8	686.5
Chlorine (Cl)...	11.2	36.2	2.7	36.8	131.0
Total dissolved solids...	252.	369.	286.	312.	1218.

1. Wausaukee River, Wausaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July 10, 1897.
2. Well of C. & N. W. Ry. Co., Marinette, Analyst, G. M. Davidson, March, 1888.
3. Well of C. M. & St. P. Ry. Co., Ellis Junction. Analyst, Chemist, C. M. & St. P. Ry. Co., July 14, 1891.
4. Well of C. M. & St. P. Ry. Co., Pembine. Analyst, Chemist, C. M. & St. P. Ry. Co., Oct., 1902.
5. Two wells of C. M. & St. P. Ry. Co., Ellis Junction. Analyst, G. N. Prentiss, March 1, 1900.
6. Well of C. M. & St. P. Ry. Co., Amberg. Analyst, Chemist, C. M. & St. P. Ry. Co., July 28, 1891.
7. Well of C. M. & St. P. Ry. Co., Wausaukee. Analyst, G. N. Prentiss, Mar. 28, 1905.
8. Well of C. M. & St. P. Ry. Co., Coleman. Analyst, Chemist, C. M. & St. P. Ry. Co., April 17, 1891.
9. Well of C. M. & St. P. Ry. Co., Coleman. Analyst, Chemist, C. M. & St. P. Ry. Co., July 15, 1891.
10. Well of C. M. & St. P. Ry. Co., Coleman. Analyst, G. N. Prentiss, Mar. 27, 1905.
11. Artesian flowing well of I. Stevenson, Marinette. Analyst, W. W. Daniells.

Marquette County

Marquette county, located in the south central part of the state, has an area of 451 square miles and a population of 10,741. About 91.2 per cent of the county is in farms of which 47.6 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is very gently undulating and is characterized by many level sandy tracts ana broad marshy areas. The broad valley of the Fox river lies across the southeastern part of the county. Mecan river, Montello creek and Neenah creek flowing southeast are the principal tributaries of the Fox. Buffalo Lake, a shallow expansion of the Fox river, constitutes an important part of the river in Marquette county.

The highest land lies in the northwestern part of the county, the general slope being to the southeast. The limestone bluffs in the northwest corner reach an elevation of about 1,300 feet above sea level, about 150 feet above the general altitude of the surrounding area. Observatory Hill, a high mound of porphyry in the southeastern part, reaches an altitude of 1,100 feet, about 100 feet above the general level of the sandstone and drift uplands. In general, the valley of the Fox has an altitude of about 780 feet, while the upland areas generally reach up to 1,050 and 1,100 feet in the northeastern part, and from 1,100 to 1,200 feet in the northwestern part.

GEOLOGICAL FORMATIONS

The geological formations are mainly the Upper Cambrian (Potsdam) sandstone and the surface deposits of drift and alluvium. A few outcrops of Pre-Cambrian porphyry and granite widely separated lie along the Fox river valley. The highest mounds in the northwestern part of the county are capped with the Lower Magnesian limestone. The geological structure is illustrated in Fig. 39, which shows a cross section of both Marquette and Green Lake counties.

The thickness of the geological formations varies considerably in different parts of the county, on account of unequal erosion. The usual range in thickness of the various formations may be summarized as follows:

Probable range in thickness of formations in Marquette County.

Formation.	Thickness.
	Feet.
Suface formation	0 to 300
Lower Magnesian limestone (only on mounds in N. W. part)	0 to 30
Upper Cambrian (Potsdam) sandstone	0 to 750
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing horizons are the Upper Cambrian (Potsdam) sandstone and overlying surface deposits of gravel and glacial drift. Most of the wells in the county are relatively shallow.

FLOWING WELLS

Along the Fox river are many artesian flowing wells in the gravel and sand. In the village of Oxford the wells are from 12 to 30 feet deep, some of which are flowing. In Packwaukee, there are flowing wells near the lake, the water rising 5 or 6 feet above the level of Lake Buffalo. In Montello, Endeavor and Westfield are many flowing wells as described below and on the following page.

WATER SUPPLIES FOR CITIES AND VILLAGES

Montello.—The village of Montello. located at the east end of Lake Buffalo, has a population of 1,104. In Montello are at least 12 good flowing wells, ranging in depth from 80 to 140 feet. The wells are in the valley of Montello creek, which enters the lake at this point. They are the same type as those described on the Fox river in the vicinity of Berlin. It is very likely that other flows will be obtained about Buffalo Lake, particularly on the marshy flats and lowlands surrounding the lake and along Montello creek and its tributaries.

Endeavor.—At the upper end of Buffalo Lake, in the vicinity of Endeavor, several artesian flows have been obtained during recent years. The wells range in depth from 20 to 40 feet. There is little doubt that in the future many more flowing wells will be drilled in this locality and farther up the Fox river. How much farther up the river these conditions extend has not been determined, but about Buffalo Lake and the Fox river, south of the lake, the low flats and marshy lowlands are the most favorable areas for obtaining flows. The local conditions will determine the elevations at which the flows may be obtained.

Westfield.—The population of Westfield is 729. Within the village of Westfield, Sec. 12, T. 16, N. R. 8 E., are at least 12 flowing wells, which obtain water entirely from the alluvial sand or drift. The strongest and deepest of these, that of A. F. Wooster, is 125 feet deep, and flows 12 feet above the surface. The wells are grouped in a general way along the valley of a small stream. On the south of Main street, where it runs parallel to the brow of the hill, are four good flowing wells in close proximity. Just north, across the street, perhaps 5 feet higher, are several wells parallel to the four wells above mentioned, which do not flow, and which entered rock a few feet below the surface. These wells appear to be on the edge of a buried cliff, while the flowing wells are in the alluvial filled valley.

QUALITY OF THE WATER

The mineral analyses of water supplies of the pond and from surface deposits in the vicinity of Oxford, are shown in the table. The waters analyzed are hard, of either low or very moderate mineral content, and are very probably typical for the surface waters and for waters from the surface deposits throughout the county. Waters of slightly higher content of mineral probably occur only in close association with the limestone formation.

The water from the pond, near Oxford, No. 3, contains 0.93 pounds of incrusting solids in 1,000 gallons, and that from the well on the Nunn farm, No. 5, contains 2.14 pounds in 1,000 gallons.

Mineral analyses of water in Marquette County.

(Anaylses in parts per million.)

	Lakes.				Surface deposits.
	1.	2.	3.	4.	5.
Depth of well ... feet	...	...	...	...	125
Silica (SiO_2)	6.1	10.9	8.0	3.9	13.7
Aluminium and iron oxides (Al_2O_3 + Fe_2O_3)	1.7	0.5	2.5	.6	2.7
Calcium (Ca)	40.4	38.8	36.6	24.2	47.2
Magnesium (Mg)	26.6	17.9	21.4	12.8	35.2
Sodium and potassium (Na+K)	1.3	1.6	1.3	6.9	.8
Carbonate radicle (CO_3)	119.3	98.1	101.5	65.8	149.7
Sulphate radicle (SO_4)	11.2	6.0	6.1	3.4	7.4
Chlorine (Cl)	2.1	2.5	2.0	10.6	1.3
Organic matter	8.5	6.8	...	...	...
Total dissolved solids	209.	176.	179.	128.	258.

1. Buffalo Lake, Fox River, Analyst, G. M. Davidson, Jan. 22, 1912.
2. Mill Pond, Oxford, Analyst, G. M. Davidson, Jan. 22, 1912.
3. Mill Pond, Oxford, Analyst, G. M. Davidson, April 27, 1911.
4. Pond ½ mile S. W. Oxford station, Analyst, G. M. Davidson, April 27, 1911.
5. Well of Nunn farm, Oxford, Analyst, G. M. Davidson, April 27, 1911.

MILWAUKEE COUNTY

Milwaukee County, located in the southeastern part of the state, has an area of 228 square miles and a population of 433,187. Most of the population is in the city of Milwaukee and in the outlying suburbs. About 65.2 per cent of the rural district is under cultivation.

SURFACE FEATURES

The surface of Milwaukee county is a gently undulating plain, without prominent relief, sloping eastward towards Lake Michigan. The county is drained by the Milwaukee and Menominee rivers, flowing in-

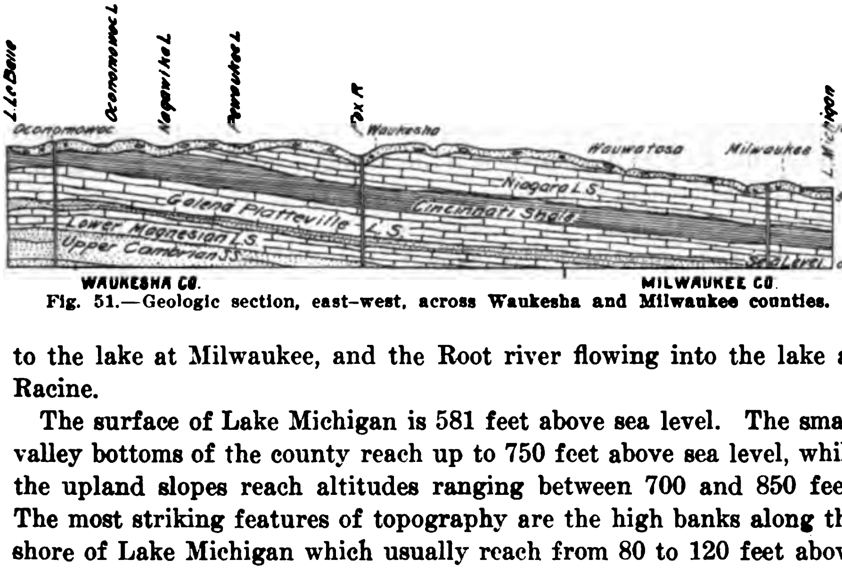

Fig. 51.—Geologic section, east-west, across Waukesha and Milwaukee counties.

to the lake at Milwaukee, and the Root river flowing into the lake at Racine.

The surface of Lake Michigan is 581 feet above sea level. The small valley bottoms of the county reach up to 750 feet above sea level, while the upland slopes reach altitudes ranging between 700 and 850 feet. The most striking features of topography are the high banks along the shore of Lake Michigan which usually reach from 80 to 120 feet above the lake.

GEOLOGICAL FORMATIONS

The rock immediately underlying the drift is mainly the Niagara limestone. In a few places in Milwaukee and vicinity are beds of Devonian shale and limestone overlying the Niagara. The geological section of Milwaukee and Waukesha counties is illustrated in Fig. 51.

The known thickness of the surface deposits of glacial drift, alluvial and lacustrine formations ranges, from zero up to 176 feet, but it is

quite probable that the surface deposits in some places may be of much greater thickness, perhaps 250 or 300 feet. The thickness of the Niagara is also variable on account of erosion, the known range in thickness being between 230 and 425 feet. The maximum thickness in the county probably does not exceed 450 to 500 feet.

The thickness of the Devonian limestone deposits in Milwaukee is only 25 feet at the Milwaukee Cement quarry, where this formation is exposed, but some well records appear to show the presence of at least 138 feet. The thickness of the formations underlying the Niagara limestone, viz. the Cincinnati shale, the Galena-Platteville (Trenton) limestone, the St. Peter sandstone, the Lower Magnesian limestone and the Upper Cambrian (Potsdam) sandstone is shown in the well records of deep wells in the city of Milwaukee, cited on the following pages.

In most of these deep wells there appears to be no limestone in the horizon of the Lower Magnesian group, the entire strata below the Trenton being sandstone, and for this reason it is practically impossible to distinguish the exact boundaries between the formations below the Trenton in the deep wells. That St. Peter sandstone in place of Lower Magnesian limestone should largely or entirely occupy the usual horizon of the Lower Magnesian is quite common as observations show a similar development in various other parts of the state.

The probable range in thickness of the formations in Milwaukee county may be summarized as follows:

Range in thickness of geological formations in Milwaukee County.

Formations.	Thickness.
	Feet.
Surface formations	0 to 300
Devonian limestone or shale	0 to 150
Niagara limestone	200 to 500
Cincinnati shale	140 to 200
Galena-Platteville (Trenton) limestone	250 to 350
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	800 to 900
Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

All of the geological formations are drawn upon for water supplies but the most important sources are the surface deposits of drift and the Niagara limestone. It is only in the deep artesian wells in Milwaukee and suburbs that the water-bearing strata underlying the Niagara is drawn upon.

A very large number of wells in the rural districts obtain their water supply from the drift at depths less than 80 feet, only a few wholly in drift exceeding this depth. The supply in the drift is generally obtained from gravel beds at the contact of the drift and the underlying rock, at which horizon gravel often occurs. These drift wells have furnished a large part of the water supply since the settlement of the country, but farmers now often find this source to be inadequate, and during the last few years the drift wells have been deepened and now draw water from the underlying rock.

Wells drawing their supply from the underlying limestone range in depth from 20 to 365 feet, and penetrate the rock from 1 to 270 feet. Although they are usually more expensive than the drift wells, their water is of better quality, and their supply is larger and more constant.

FLOWING WELLS

Flowing wells have been obtained in both the surface deposits and the underlying rock. Only a relatively few flowing wells of shallow depth have been obtained from the drift in Milwaukee and vicinity. These wells depend on local conditions, and generally derive their supply from a sand or gravel stratum that underlies a bed of relatively compact clay. Adjacent wells often interfere with each others flow as illustrated by the flowing wells in the southeastern part of Sec. 33, T. 8, R. 21 E., where one well flowed until another well 80 rods distant was bored at a somewhat lower level. There are a few surface flowing wells in Sec. 6 of the town of Wauwautosa, one at a place one-fourth mile north of Butler, one at the St. Francis Art Institute and one on the Green Bay road one mile east of North Milwaukee.

Flowing wells in the Niagara limestone are not known to occur in the immediate vicinity of Milwaukee, but flows of this type occur in considerable abundance in the northwest part of the county.

At Granville, wells somewhat similar to those at South Germantown in Washington County are obtained. The water at Granville does not rise as high above the surface as at South Germantown.

Most of the wells in this vicinity draw their water from the Niagara limestone at various depths. Flowing wells are struck on low ground all the way from West Bend to points south of Granville.

Record of flowing well owned by Peter Schmidt, Granville.

Formation.	Thickness.
	Feet.
Soil	2
Blue clay	88
Niagara limestone (not through)	60
Total depth	150

Deep artesian flowing wells obtaining their supply from the sandstone strata underlying the Galena-Platteville (Trenton) limestone occur in many favorable localities in Milwaukee and the surrounding suburbs, some of which are referred to on page 79, and are more fully described under the water supplies for cities and villages. The head of several of these artesian wells is given in Table No. 18. The head of the deep flowing wells in Milwaukee, when first drilled ranged from 50 to over 100 feet above Lake Michigan. Many of the wells that originally flowed have ceased flowing or have much lower head on account of improper casing and increased draft upon the artesian reservoir.

SPRINGS

Springs occur in various parts of the county, most of which have their source in the drift, but some have their source in the Niagara limestone. There are several well known mineral springs locatd at Wauwautosa, among which may be mentioned the Nee-Ska-Ra spring and the Elim Mineral Spring which supply the market at the present time. Waters for the market have been supplied from a large number of mineral springs in Milwaukee county, among which may be mentioned the Eureka spring and the Sylvan Spring of Milwaukee; Hackett's Spring at Hales Corners; Schweichardt's Spring, Sparkling Spring and Castalia Spring at Wauwautosa, and the "Soda Lithia" spring northwest of Fussville on the Fond du Lac Road.

WATER SUPPLIES FOR CITIES AND VILLAGES

Milwaukee.—Milwaukee, situated on Lake Michigan, at the mouth of the Menomonee and Milwaukee rivers, has a population of 373,857. The city water supply is obtained from Lake Michigan at a point about a mile and a half from shore. The sewage, without purification, empties into the Milwaukee river and thence into the lake. About 90 per

cent of the houses are connected with the water supply and sewerage systems. The average daily pumpage in 1914 was 47,913,000 gallons.

There has been much discussion at various times concerning the purity of Milwaukee's public supply of drinking water. While it is very generally conceded that the supply is not entirely free from pollution, it is also generally contended that the supply is not dangerous because no cases of typhoid have been directly traced to the water supply, though various epidemics of intestinal troubles may be traceable to it.

The source of the pollution of the water is due to the city sewage that is emptied into the lake. While the intake for the water supply is located out in the lake about a mile and a half off shore, a certain amount of polluted water reaches the intake, the amount of pollution depending upon the direction of prevailing winds with reference to the location of the sewage outlets and the water intake. Under the present method of emptying the city sewage into the source of the water supply there is constant danger to the health of the city. As the amount of sewage emptied into the lake increases on account of the increase in population there is constantly increased danger in using the lake water supply. Some efficient method of disposal should be adopted and also the intake should be extended into the lake to a distance beyond which polluted water does not extend. The recent report of the special sewage commission recommends that the raw sewage be no longer emptied into the lake.

The future growth of the city would require the provision for water supply and sewage as estimated by G. A. Geiger in the following table:

Estimated future requirements of water supply and sewage in Milwaukee.

Year.	Population.	Daily consumption of water in gallons.	Total sewage per day estimated.	Total sewage per day estimated by commission.
1910	375,000	42,000,000	60,000,000	61,000,000
1920	480,000	54,000,000	77,000,000	....
1930	585,000	67,000,000	96,000,000	100,000,000
1940	720,000	84,.00,000	121,000,000	....
1950	850,000	102,000,000	146,000,000	155,000,000

When the present pumping station was located at the foot of North avenue on the lake shore of Lake Michigan, in 1871, an intake, consisting of a 36-inch cast iron pipe, starting at the pumping station and running out into the lake at right angles to the shore a distance of 2,000 feet was laid. At that time the building of sewers had just begun and

the water supply was pure and wholesome. As the building of sewers continued from year to year, discharging their contents into the river and then into the lake, the water at the intake became contaminated and finally this intake had to be abandoned.

A new intake, consisting of a $7\frac{1}{2}$-foot underground tunnel 3,200 ft. long, ending in a shaft from which extend two 5-foot pipes 5,000 ft. long laid on the bottom of the lake, was started in 1890 and finished in 1895. The approximate cost[1] of constructing this intake was $575,000. This intake starts at the pumping station and runs due east out into the lake, a distance of 8,200 feet, ending in a submerged crib and taking water at a depth of 50 feet below the lake surface. While this new intake gave pure water at the time, it is now occasionally contaminated, due to sewage entering the lake, and it has been decided that this intake will also have to be abandoned.

It was urged that an entire new plant, consisting of an intake and pumping station, with new machinery and force mains, is necessary, and that it should be located so that it will supply the city with pure and good water for a long time to come. That, however, cannot be done by going only a short distance away from the present contaminated intakes.

The proper location for this new intake was said to be at Fox Point, which would place it about ten (10) miles away from the mouth of the river, and make the supply safe for a number of years. If in the meantime the sewage of the entire city is purified before it reaches the lake, the city would have an inexhaustible, permanent pure supply of drinking water.

The present city administration of 1914–15, realizing the need of a better water supply, have begun the construction of the third intake located about a mile north of the present one. The third intake extends 6,300 feet northeast of Lake Park from a point opposite Linwood Ave. and consists of an underground tunnel, 12 feet in diameter and 4,000 feet long, ending in an intake shaft, from which extend 4 lines of 6-foot pipe, 2,300 feet long, laid on the bottom of the lake and ending in submerged cribs at depth of 60 feet.

This new intake located about 4 miles from the mouth of the river, according to past experience, may furnish pure water for a short time, probably only for a few years, as the location is too close to the mouth of the river. If the city sewage is purified, however, the pollution of the new source of supply may be prevented.

Many artesian wells for private water supplies have been drilled

[1] Eng. News, vol. 34, p. 187–190, 1895.

in or near Milwaukee, but no accurate information can be obtained concerning most of these wells, and little is known of their present condition. Mr. F. M. Gray, well driller, reports that the Lower Magnesian limestone is absent in many wells, and that according to the usual interpretation, the St. Peter rests directly upon the Potsdam. For other records, however, it appears that some limestone of the Lower Magnesian horizon is present in places. The artesian head has decreased considerably, but the exact amount could not be determined since the variation was not consistent. The heavy drafts made upon the wells at the breweries and other manufacturing establishments result in bringing about the same conditions here as at Green Bay. When so many wells are grouped within a small radius, as is the case at some of the breweries, they greatly interfere with one another. If heavily pumped they will draw upon the neighboring wells. Many of the wells were originally packed to insure good flows, and the failure of those may be due entirely to displacement of the packing.

In most of the well records the Lower Magnesian limestone has not been recognized, and the statements of the most experienced and reliable drillers generally agree in this regard. Thus it would seem that this formation is either not present or is mainly sand and shale and lacking the limestone beds in this locality. In drilling the third artesian well at the Forest Home Cemetery in 1902, a stratum very closely resembling the Lower Magnesian limestone was struck. The drilling was given up on account of a stratum of caving sand.

Section[1] of Well at Forest Home Cemetery, Milwaukee.

Formation.	Thickness.
	Feet.
Drift and fine sand	100
Niagara: shell rock	80
hard limestone	230
Cincinnati shale	190
Galena-Trenton limestone	250
St. Peter sand and Lower Magnesian	285
Potsdam. limestone, hard	40
sandy limestone	60
caves badly: sand runs in (cased)	131
Total depth	1,316

[1] (Authority of F. P. Miller, driller.)

The thickness of the St. Peter combined with Lower Magnesian indicates that the limestone (40 feet) might be the Mendota limestone. The "shell rock" in this record may be Devonian shale, the Milwaukee formation. It will be of interest to compare with this record a rather complete record of E. P. Allis' well, drilled in 1902 at West Allis.

Section of Well of E. P. Allis at West Allis.

Formation.	Thickness.
	Feet.
Pleistocene:	
Clay	18
Blue clay	54
Gravel	58
Niagara:	
Limestone	285
Cincinnati:	
Shale	160
Galena-Trenton:	
Limestone	246
St. Peter: (?)	
Sandstone	225
Potsdam:	
Red marl	25
Red sand	120
Sand	60
White sand	49
Total depth	1,300

The following log of the Pfister and Vogel Leather Co. well shows the detailed character of the Pleistocene formation in Milwaukee. The well is located on Vogel's Island, on 3rd Ave. south of Canal St. The samples, described by F. T. Thwaites, are on file in the State University.

Log of Well of Pfister & Vogel Leather Co., Milwaukee.

Formation.	Depth.	Thickness.
	Feet.	Feet.
Pleistocene:		
Marsh muck and small shells	0 - 5 5 - 12	
Gray-brown calcareous clay	12 - 14	
Marsh muck, shells and fine brown calcareous clay	14 - 30	
Soft gray calcareous clay	30 - 53	
Blue water-bearing sand	53 - 55	
Gray calcareous clay	55 - 65	
"Hard pan", hard gray sand, waterbearing	65 - 70	
Gray pebbly clay	70 - 90	
Sandy soft gray clay	90 - 94	
"Till" light blue hard calcareous clay	96 - 103	
Sandy, pebbly gray clay	103 - 112	
Very hard, blue sandy calcareous clay	112 - 135	
Gray, soft, calcareous clay	135 - 146	
Very hard blue calcareous clay	146 - 150	
Soft sandy gray clay	150 - 167	
Soft blue clay (poor sample)	167 - 174	
Soft gray sandy clay	174 - 177	
Hard blue clay ("till")	177 - 183.5	183.5
Niagara limestone:		
Hard gray lime tone	183½- 193	
Softer and lighter limestone	193 - 201	
No samples below this.		
Limestone	201 - 435	251.5
Cincinnati shale	435 - 635	200
Galena-Platteville (Trenton) limestone	635 - 860	225
St. Peter sandstone	860 -1,167	307
Lower Magnesian (marl)	1,167 -1,195	28
Potsdam sandstone	1,195 -1,700	505
Total depth		1,700

The sections in the table below leave very little doubt of either the absence or very slight thickness of the Lower Magnesian limestone beds. The St. Peter sandstone is encountered usually between 800 to 1,000 feet, but it is impossible to state how much of the sandstone should be classed as St. Peter and how much as Lower Magnesian and Potsdam where the formations are similar in character.

Sections of Wells in and about Milwaukee.

	Milwaukee.				Wauwatosa.					West Allis	
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Elevation of curb	590	590	......	670	650	660	680	710	660	728	730
Drift	176	170	165	160	40	100	70	100	40	142	130
Devonian	......	......	......	122	......	......	......	......	......	......	......
Niagara limestone	314	267	310	340	340	350	425	......	280	254	285
Cincinnati shale	170	165	210	180	160	175	175	950	140	174	160
Galena-Trenton limestone	245	253	250	330	330	250	375	......	320	260	247
St. Peter sandstone	602	193	686	958	660	425	120	450	577	2	225
Potsdam sandstone	......	......	......	......	......	......	685	......	......	......	254
Total depths	1,497	1,048	1,621	2,100	1,530	1,300	1,850	1,500	1,357	832	1,300

I. E. P. Allis.
II. Market Square.
III. Forest Home Cemetery.
IV. Lake Park.
V. Miller Brewing Co.
VI. Mr. Dixon.
VII. Story Bros.
VIII. Mr. Ludington.
IX. Wauwatosa Water Works.
X. E. P. Allis.
XI. E. P. Allis.

In the illustration,[1] Fig. 52, artesian well sections from Waukesha to Milwaukee show the underground geologic relations.

Cudahy. The city of Cudahy, population 3,691, has a public water supply obtained from Lake Michigan, from the Milwaukee water works. The average daily pumpage is about 300,000 gallons. A sewage system is installed, the sewage being emptied into the lake. About 40 per cent of the houses are connected with the water supply, and about 60 per cent of the houses are connected with the sewage system.

South Milwaukee. Population 6,092. The city water supply is obtained from Lake Michigan through two intakes extending about a mile from the shore, at depths of 17 and 26 feet. The sewage empties into the lake, about four-fifths of a mile from the intake for the water supply. About 75 per cent of the houses are connected with the water supply and 50 per cent of the houses are connected with the sewage system. The average daily pumpage is 476,000 gallons.

North Milwaukee. Population 1,860. The village has a water supply obtained through the Milwaukee system and have plans under way

[1] After Wm. C. Alden, Milwaukee Geologic Folio, U. S. Geol. Survey, Folio No. 140.

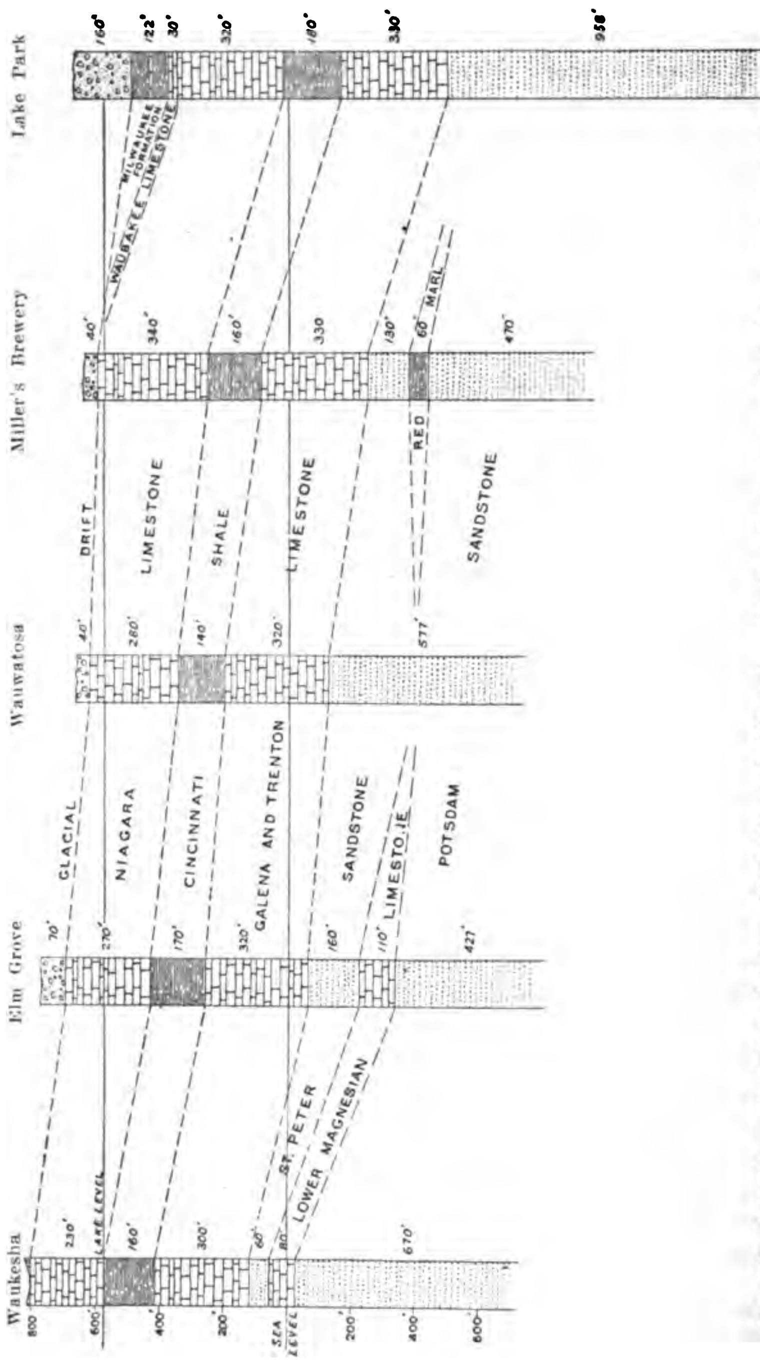

Fig. 52.—Artesian well sections between Waukesha and Milwaukee showing the underground geologic relations. (After Alden)

for a sewage system. It is proposed to install a plant to treat the sewage before discharging it into a small tributary of the Milwaukee river.

West Allis. West Allis, a suburb of Milwaukee, has a population of 6,645. The public water supply is obtained through the Milwaukee city system. A sewage system is installed.

East Milwaukee. East Milwaukee, population 707, obtains its public water supply through the Milwaukee city system.

Wauwatosa. Population 3,346. This city, a suburb of Milwaukee, has a public water supply derived from a 10-inch flowing well 1,357 feet deep, reaching the St. Peter sandstone. The elevation of the curb is 660 feet, the head being 27 feet above the surface. The water flows into a covered reservoir, from which it is pumped into the city mains. The daily capacity of the flow is 516,000 gallons, and the average daily pumpage is about 212,000 gallons. The sewage is treated by septic tanks and sand filters before emptying into the Menomonee river. Most of the population utilize the public water supply and sewage system.

QUALITY OF THE WATER

The water of many of the springs about Milwaukee have been drawn upon at various times for both domestic and medicinal purposes. See table of mineral analyses. Most of the spring waters have only a moderate content of mineral, though in respect to hardness, all would be classed as hard waters. The Eureka Spring water, however, is unusual in its very high mineralization, and is distinctly a salt water. The source of most of these springs is not known. Some of them may be in the Niagara limestone, but most of them are probably in the surface formation. The source of the Elim Spring is in a gravel bed. It is quite possible that the Eureka Spring water is obtained from a deep well rather than a spring, as saline water is characteristic of many of the deep wells in this locality.

The water of Lake Michigan is of low mineral content, though it is classed as medium hard water as defined in this report. The water of Milwaukee river is higher in mineral content than the lake water, but somewhat lower than that of the springs and the wells. Several of the analyses of the waters of the Menomonee river, especially, Nos. 6 and 7, indicate extreme pollution, due to refuse from the sugar factory, at Menomonee Falls.

The water of the relatively shallow wells in Milwaukee, with source of supply either in the surface formation or the underlying Niagara limestone, have a moderate content of mineral, but the two railroad wells at the Granville station one in the surface deposits, No. 39, the

other in the Niagara limestone, No. 47 have a high content of mineral, and are very hard waters. The waters of the very deep wells, those obtaining their supply from the St. Peter and Potsdam sandstone, are very generally much higher in mineral content than the waters from shallow wells in the surface and Niagara formations.

Of 6 waters analyzed from wells in the surface deposits 1, or only 16.6 per cent, contains more than 500 parts per million of mineral content; of 15 waters from the Niagara limestone 5, or 33.3 per cent, contain more than 500 parts per million of mineral; and of 18 waters analyzed from the St. Peter and Potsdam sandstones, 12, or 66.6 per cent, contain more than 500 parts per million of mineral matter. While only a few of the deep-seated waters appear to be sufficiently high in chlorine to be salty, all contain relatively large amounts of sulphate.

In prospecting for underground water supplies in Milwaukee, the above indicated progressive increase in mineral content in passing from the surface deposits down to the Potsdam sandstone, should be taken into consideration. All the underground waters of Milwaukee county are either hard or very hard waters. The best supply for steam making in boilers is the lake water.

There are 1.04 pounds of incrusting solids in 1,000 gallons of Lake Michigan water, in No. 21; 2.68 pounds in 1,000 gallons of the water of the Menomonee Creek, near Granville, No. 5; and 3.66 pounds in 1,000 gallons of the water of the deep well at Rawson, No. 68.

Mineral analyses of water in Milwaukee County.

(Analyses in parts per million.)

	Milwaukee River.				Menomonee River.		
	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2)	5.5	4.80	5.83	....	16.9	9.95	10.09
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	....	2.06	2.06	7.2	1.0	44.50	2.56
Calcium (Ca)	47.4	42.30	43.42	44.1	91.2	356.87	110.76
Magnesium (Mg)	29.6	19.10	20.70	26.5	31.7	79.78	51.73
Sodium and potassium (Na+K)	4.0	6.62	6.00	9.6	3.7	18.20	4.96
Carbonate radical (CO_3)	140.4	93.13	96.70	131.2	204.9	675.17	216.97
Sulphate radical (SO_4)	11.1	29.47	31.25	8.0	21.5	91.61	122.86
Chlorine (Cl)	2.4	10.18	9.42	8.9	1.9	28.15	7.71
Organic matter	....	81.85	60.20	....	....	2,505.82	159.94
Total dissolved solids	239.9	207.66	215.38	235.5	373.8	1,304.23	527.64

1. Milwaukee River above dam. Analyst, G. Bode, Geology of Wisconsin, Vol. 2, p. 32, 1877.
2. Milwaukee River, Milwaukee, ¾ mile south of C. & N. W. Ry. Station. Analyst, G. M. Davidson, Nov. 8, 1911.
3. Milwaukee River, Milwaukee, ¾ mile south of C. & N. W. Ry. Station. Analyst, G. M. Davidson, Nov. 8, 1911.
4. Milwaukee River at Sanderson's Mill, Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 22, 1888.
5. Menomonee Creek at Granville. Analyst, G. M. Davidson, July, 1897.
6. Menomonee River at Butler, 15 miles below beet sugar factory at Menomonee. Analyst, G. M. Davidson, Feb. 7, 1912.
7. Menomonee River at Butler, 7 miles below beet sugar factory at Menomonee. Analyst, G. M. Davidson, Nov. 3, 1911.

***Mineral analyses of water in Milwaukee County*—Continued.**

	Menomonee River.						
	8.	9.	10.	11.	12.	13.	14.
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	10.6	2.7	undt.	4.1	undt.	undt.	undt.
Calcium (Ca)	74.4	104.0	116.0	118.7	125.7	51.8	75.1
Magnesium (Mg)	35.5	37.5	37.9	45.2	48.7	20.0	29.3
Sodium and potassium (Na+K)	11.3	18.2	undt.	19.4	undt.	10.9	11.4
Carbonate radicle (CO_3)	154.5	162.0	165.1	184.1	180.8	90.8	134.4
Sulphate radicle (SO_4)	75.4	150.8	162.9	181.8	183.9	79.9	103.6
Chlorine (Cl)	13.9	18.7	undt.	19.4	undt.	undt.	undt.
Total dissolved solids	375.6	493.9	481.9	572.7	534.1	252.9	353.8

	Menomonee River.					Lake Michigan.	
	15.	16.	17.	18.	19.	20.	21.
Silica (SiO_2)	....	....	....	....	....	16.0	5.1
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	undt.	undt.	undt.	undt.	undt.	....	0.3
Calcium (Ca)	68.3	115.5	113.4	16.4	74.9	34.0	32.1
Magnesium (Mg)	34.0	46.8	47.2	7.2	48.2	10.2	10.9
Sodium and potassium (Na+K)	15.3	16.9	21.8	3.0	11.2	1.5	3.1
Carbonate radical (CO_3)	166.4	184.8	178.5	38.6	181.2	72.0	73.4
Sulphate radical (SO_4)	62.6	200.9	218.2	12.9	83.0	6.0	6.8
Chlorine (Cl)	undt.	undt.	undt.	undt.	14.3	3.0	2.3
Total dissolved solids	346.6	564.9	579.1	78.1	412.8	142.7	134.

8. Menomonee River at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 12, 1888.
9. Menomonee River at bridge foundry, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 6, 1899.
10. Menomonee River at bridge foundry, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 12, 1899.
11. Menomonee River at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 6, 1899.
12. Menomonee River at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 12, 1899.
13. Menomonee River at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 2, 1899.
14. Menomonee River at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 27, 1899.
15. Menomonee River at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., June 2, 1899.
16. Menomonee River, 38" deep at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July 28, 1899.
17. Menomonee River 29" deep at paint shop, West Milwaukee. Analyst, Chemist C. M. & St. P. Ry. Co., Dec. 6, 1899.
18. Menomonee River at paint shop, West Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 8, 1900.
19. Menomonee River near Falks, Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., June 6, 1910.
20. Lake Michigan. Analyst, G. Bode, Geology of Wisconsin, Vol. 2, p. 32, 1877.
21. Lake Michigan. Analyses of water from the lake at Chicago adopted as standard for comparison by C. & N. W. Ry. Co. Analyst, J. H. Long.

Mineral analyses of water in Milwaukee County—**Continued.**

	Lake Michigan.					Springs.	
	22.	23.	24.	25.	26.	27.	28.
Silica (SiO_2)	6.6	5.6	....	....	....	11.78	16.0
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	1.6	1.9	1.5	4.5	undt.	1.32	5.0
Calcium (Ca)	33.6	26.6	31.6	34.0	31.8	74.72	70.4
Magnesium (Mg)	11.9	11.3	10.5	11.2	10.6	28.12	32.0
Sodium and potassium (Na+K)	2.2	6.1	3.4	4.8	6.7	3.75	11.3
Carbonate radical (CO_3)	66.7	68.0	70.2	76.6	71.0	174.83	167.4
Sulphate radical (SO_4)	21.6	8.0	6.9	8.1	9.0	15.46	12.8
Chlorine (Cl)	3.5	3.5	2.9	3.1	7.2	3.04	2.4
Organic matter	Trace.	1.0	....	....	....	....	....
Total dissolved solids	148.0	131.0	127.0	142.3	136.3	313.07	317.3

	Springs.						Creek and surface well.
	29.	30	31.	32.	33.	34.	35.
Silica (SiO_2)	35.0	12.4	13.7	123.0	10.0	10.4	....
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	3.6	2.0	2.9	188.0	....	3.4	7.0
Calcium (Ca)	82.0	83.4	66.8	163.6	90.0	133.5	41.8
Magnesium (Mg)	44.3	36.3	32.2	52.9	38.8	64.5	37.4
Sodium and potassium (Na+K)	8.7	11.1	9.0	1,452.7	29.5	51.0	24.3
Carbonate radical (CO_3)	236.0	178.6	180.3	447.4	241.0	268.1	60.9
Sulphate radical (SO_4)	6.8	58.1	5.4	185.5	33.7	209.6	180.8
Chlorine (Cl)	2.4	17.1	9.9	2,030.0	9.6	81.6	14.3
Total dissolved solids	418.8	390.0	320.2	4,643.1	452.6	772.1	366.5

22. Lake Michigan. City water supply of South Milwaukee. Analyst, Dearborn Drug & Chemical Co., March 5, 1912.
23. Lake Michigan. Direct from city mains, Milwaukee. Analyst, Dearborn Drug & Chem. Co., Sept. 6, 1907.
24. Lake Michigan. City supply for Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July, 1889.
25. Lake Michigan. City supply for W. Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Dec. 15, 1894.
26. Lake Michigan, Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 13, 1907.
27. Ellm Spring, 1½ miles west of Brown Deer. Analyst, A. S. Mitchell, Aug. 4, 1896.
28. Hacketts Spring, Hales Corners. Analyst, G. Bode. Geology of Wisconsin, Vol. 2, p. 32, 1877.
29. Schweickardt's Spring, Wauwatosa. Analyst, G. Bode. Geology of Wisconsin, p. 32, vol. 2, 1877.
30. Nee-ska-ra Spring, Wauwatosa. Analyst, Frank Kramer, Jan., 1912.
31. Nee-ska-ra Spring, Wauwautosa. Analyst, J. H. Long.
32. Eureka Spring, Milwaukee. Analyst, G. Bode. Geology of Wisconsin, vol. 2, p. 31, 1877.
33. Siloam Spring, Milwaukee. Analyst, G. Bode. Geology of Wisconsin, vol. 2, p. 31, 1877.
34. Spring near C. & N. W. R. Pass. Depot, Milwaukee. Analyst, G. M. Davidson, July 16, 1898.
35. Creek and Well at North Milwaukee, C. M. & St. P. Ry. Co. Analyst, G. N. Prentiss, July 9th, 1897.

***Mineral analyses of water in Milwaukee County*—Continued.**

	Creek and surface well.		Surface deposits.				
	36.	37.	38.	39.	40.	41.	42.
Depth of well .... feet..	....	....	26	24	24	30	42
Silica (SiO_2)	....	....	....	11.9	undt..	....	....
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	3.8	undt.	2.7	1.0	....	1.5	5.1
Calcium (Ca)	49.1	54.9	53.6	151.3	66.6	72.4	57.6
Magnesium (Mg)	27.4	27.7	24.0	53.4	39.0	38.1	35.4
Sodium, and potassium (Na+K)....	48.5	55.5	46.5	116.4	33.3	30.4	32.3
Carbonate radical (CO_3).. .	87.5	94.9	87.6	343.7	150.4	168.4	143.2
Sulphate radical (SO_4)	167.1	204.8	174.0	146.5	143.5	109.0	106.0
Chlorine (Cl)	6.5	undt.	3.5	87.8	undt.	6.2	6.7
Total dissolved solids.......	389.9	437.8	391.9	912.0	432.8	426.0	386.3

	Surface deposits.		Niagara limestone.				
	43.	44.	45.	46.	47.	48.	49.
Depth of well .... .. feet..	....	28	66	130	140	73	52
Silica (SiO_2)	12.50	....	....	28.4	....	....	....
Aluminum and iron oxides $Al_2O_3+Fe_2O_3$)	1.54	2.7	....	....	....	2.6	1.4
Calcium (Ca)	93.50	53.6	36.6	55.5	155.6	66.5	52.4
Magnesium (Mg)	55.84	24.0	36.4	36.3	49.8	36.9	24.5
Sodium and potassium (Na+K)	4.99	46.5	29.6	15.3	6.9	34.0	43.1
Carbonate radical (CO_3)	228.94	87.6	129.0	172.8	173.7	148.5	85.6
Sulphate radical (SO_4)	78.07	174.0	17.3	22.5	295.8	132.4	169.0
Chlorine (Cl)	7.71	8.5	32.8	2 6	7.0	3.7	4.3
Organic matter..	36.49	....	....	....	....	....	....
Total dissolved solids...	483.09	391.9	281.7	333.4	688.8	424.6	380.3

36. Creek and well at North Milwaukee, C. M. & St. P. Ry. Co. Analyst, G. N. Prentiss, July 23, 1897.
37. Creek and well at North Milwaukee, C. M. & St. P. Ry. Co. Analyst, G. N. Prentiss, Feb. 12, 1899.
38. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July 8, 1889.
39. Well of C. & N. W. Ry. Co. at Granville. Analyst, G. M. Davidson, July 23, 1897.
40. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, G. N. Prentiss, Feb. 5, 1900.
41. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, G. N. Prentiss, Dec. 19, 1894.
42. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, G. N. Prentiss, May 2, 1898.
43. Well of C. & N. W. Ry. Co., Coal Chute, Butler. Analyst, G. M. Davidson, Nov. 3, 1911.
44. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July 8, 1889.
45. Well of E. P. Allis, Milwaukee. Analyst, McLaren.
46. Well of Plankington, Milwaukee. Analyst, D. Fisher.
47. Well of C. M. & St. P. Ry. Co. at Granville. Analyst, Chemist, C. M. & St. P. Ry. Co., July 6, 1889.
48. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 17, 1890.
49. Well of Mr. Poppert, North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 12, 1899.

Mineral analyses of water in Milwaukee County—**Continued.**

	Niagara limestone.						
	50.	51.	52.	53.	54.	55.	56.
Depth of well......... feet..	53	65	80	80	94	94	122
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)............	undt.	undt.	undt.	undt.	undt.	undt.	undt.
Calcium (Ca)................	60.6	85.5	48.5	51.1	52.4	55.8	103.2
Magnesium (Mg)............	27.2	33.4	35.1	25.6	26.2	27.4	42.6
Sodium and potassium (Na+K)....................	55.5	48.6	50.1	45.5	46.2	44.4	59.5
Carbonate radical (CO_3)....	80.8	88.8	93.0	84.9	88.2	85.2	104.5
Sulphate radical (SO_4)......	238.3	295.5	209.2	182.1	183.4	196.7	371.1
Chlorine (Cl)..	undt.	undt.	undt.	undt.	undt.	undt.	undt.
Total dissolved solids...	462.4	551.8	435.9	389.2	396.4	409.0	680.9

	Niagara limestone.			St. Peter and Upper Cambrian sandstone.			
				Milwaukee.			
	57.	58.	59.	60.	61.	62.	63.
Depth of well......... feet..	160	160	150	1,357	1,200	1,048	1,600
Silica (SiO_2)...........	....	....	....	....	40.5	41.0	7.8
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)............	undt.	undt.	undt.	8.8	3.7	....	....
Calcium (Ca)..	209.5	183.4	63.1	132.6	109.8	195.8	218.0
Magnesium (Mg)............	79.6	76.6	37.1	26.2	18.8	103.2	27.9
Sodium and potassium (Na+K)....................	243.0	163.8	25.3	14.9	55.6	166.1	12.6
Carbonate radical (CO_3)....	41.0	43.6	168.4	129.2	102.2	503.0	133.3
Sulphate radical (SO_4)......	1,254.4	998.6	83.3	230.3	277.9	136.0	430.8
Chlorine (Cl)................	undt.	10.2	undt.	8.7	8.8	274.0	12.0
Total dissolved solids...	1,827.5	1,476.2	377.8	550.7	617.8	1,419.1	842.4

50. Well of Mr. Miller, North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co, July 31, 1899.
51. Well one block east of Poppert's, North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 15, 1899.
52. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Apr. 5, 1899.
53. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Apr. 12, 1899.
54. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Apr. 21, 1899.
55. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July 31, 1899.
56. Well of Mr. Wasserburger, North Milwaukee. Analyst, G. N. Prentiss, Feb. 15, 1899.
57. Well of Mr. Hoyt, North Milwaukee. Analyst, G. N. Prentiss, July 31, 1899.
58. Well of Mr. Hoyt, North Milwaukee. Analyst, G. N. Prentiss, Dec. 27, 1901.
59. Well of Schlitz Brewery, Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Dec. 29, 1898.
60. Well of City Water Works, Wauwautosa.
61. Well of W. H. Jacobs, Milwaukee. Analyst, G. Bode. Geology of Wisconsin, vol. 2, p. 164, 1877.
62. Market Square Well, Milwaukee. Analyst, G. Bode. Geology of Wisconsin, vol. 2, p. 31, 1877.
63. Well of C. M. & St. P. Ry. Co., Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., March 14, 1895.

Mineral analyses of water in Milwaukee County—Continued.

	St. Peter and Upper Cambrian sandstone.						
	Milwaukee.				Rawson.	N. Milwaukee.	
	64.	65.	66.	67.	68.	69.	70.
Depth of well......... feet..	1,600	1,600	....	....	1,509	1,600	....
Silica (SiO_2)..................	....	....	....	....	20.5	....	....
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)............	2.1	undt.	3.9	2.2	0.8	undt.	undt.
Calcium (Ca)................	212.1	288.6	158.2	207.5	110.7	296.6	92.9
Magnesium (Mg)............	27.6	28.5	33.6	33.2	25.9	44.6	35.2
Sodium and potassium (Na+K)....................	13.0	17.8	13.8	15.4	31.9	37.0	54.7
Carbonate radical (CO_3)....	140.1	111.4	142.6	127.8	145.5	126.0	88.3
Sulphate radical (SO_4)......	411.0	542.6	298.6	436.7	171.8	761.8	332.5
Chlorine (Cl)...........	11.7	undt.	12.6	13.3	22.2	undt.	....
Total dissolved solids...	817.6	939.9	658.3	836.1	529.3	1,266.0	603.9

	St. Peter and Upper Cambrian sandstones.						
	Butler.						
	71.	72.	73.	74.	75.	76.	77.
Depth of well......... feet..	670	1,003	1,093	1,000	1,025	1,024	665
Silica (SiO_2)............	12.70	15.07	13.30	8.88	13.01	15.09	9.78
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)............	1.71	1.02	25.21	1.03	1.71	2.06	1.03
Calcium (Ca)................	62.91	72.46	52.07	62.58	119.38	90.07	65.58
Magnesium (Mg).......	39.57	31.88	21.75	32.28	47.96	43.51	36.62
Sodium and potassium (Na+K)....................	20.60	21.61	27.02	14.56	28.78	9.20	22.42
Carbonate radical (CO_3) ...	151.62	124.82	109.27	121.06	133.57	149.50	146.57
Sulphate radical (SO_4)......	98.62	140.38	82.74	105.68	315.43	162.54	108.76
Chlorine (Cl)................	6.50	4.09	7.05	6.50	4.97	4.05	4.28
Total dissolved solids...	394.23	411.33	338.50	352.57	664.81	476.02	394.99

64. Well of C. M. & St. P. Ry. Co. shops, Milwaukee. Analyst, G. N. Prentiss, Feb. 11, 1890.
65. Well of C. M. & St. P. Ry. Co. shops, Milwaukee. Analyst, G. N. Prentiss, Feb. 11, 1890.
66. Well of Milwaukee C. W. & T. Co., Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 30, 1890.
67. Well of Milwaukee C. W. & T. Co. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 11, 1890.
68. Well of C. & N. W. Ry. Co., Rawson. Analyst, G. M. Davidson, Feb. 6, 1906.
69. Well of Meiselbach & Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 15, 1890.
70. Well on the site of old pocketbook factory, North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 13, 1902.
71. Well of C. & N. W. Ry. Co., No. 1, Butler, Wis. Analyst, G. M. Davidson, Feb. 11, 1913.
72. Well of C. & N. W. Ry. Co., No. 2, Butler, Wis. Analyst, G. M. Davidson, Dec. 24, 1912.
73. Well of C. & N. W. Ry. Co., No. 2, Butler, Wis. Analyst, G. M. Davidson, May 8, 1912.
74. Well of C. & N. W. Ry. Co., No. 2, Butler, Wis. Analyst, G. M. Davidson, Feb. 11, 1913.
75. Well of C. & N. W. Ry. Co., No. 3, Butler, Wis. Analyst, G. M. Davidson, Feb. 11, 1913.
76. Well of C. & N. W. Ry. Co., No. 3, Butler, Wis. Analyst, G. M. Davidson, Oct. 18, 1912.
77. Well of C. & N. W. Ry. Co., Yard, Butler, Wis. Analyst, G. M. Davidson, Nov. 3, 1911.

MONROE COUNTY

Monroe County, located in the west central part of the state, has an area of 915 square miles, and a population of 28,881. About 79.4 per cent of the county is laid out into farms of which 48.7 per cent is under cultivation.

SURFACE FEATURES

The surface of Monroe county is quite uneven and hilly in the southern part, but quite level in the northeastern and northern part. Valley bottom land characterizes the Lemonweir river north of Tomah

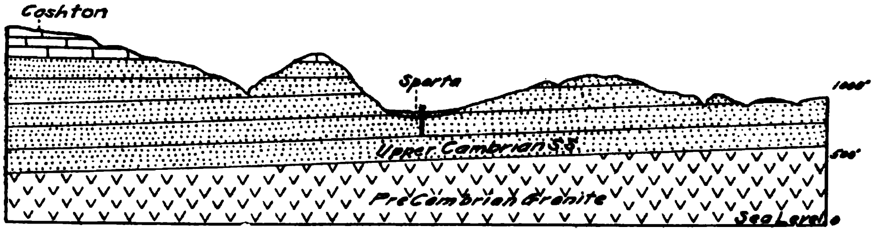

Fig. 53.—Geologic section, north-south, across western Monroe County.

and also the La Crosse river in the vicinity of Sparta. The southern part of the county is an elevated tableland deeply dissected by valleys. The valley bottoms range in altitude between 800 and 1,000 feet, and the uplands, between 1,200 and 1,350 feet.

The soils are generally sands and sandy loams in the alluvial bottoms and silt loams on the upland area.

GEOLOGICAL FORMATIONS

The geological formations are the Upper Cambrian (Potsdam) sandstone, generally outcropping in the northern half of the county and the Lower Magnesian limestone overlying the sandstone only in the southern half of the county. The county contains no glacial deposits, but the broad, flat-bottomed valleys are filled to a variable depth with alluvial sand and gravel, and the uplands are covered with a variable amount of loess. The cross section (Fig. 53) illustrates the general geological structure of the county.

The thickness of the alluvial deposits in the valley bottoms very probably reaches a maximum of 200 to 250 feet in the middle of the

old channels. The thickness of the "Potsdam" sandstone and the Lower Magnesian limestone varies betwen wide limits on account of the extensive erosion of these formations. The complete thickness of the sandstone formation is preserved only in the uplands of the southern part of the county, where overlain by the limestone. It is only in some of the deeper wells drilled in the cities and villages, located in the valley bottoms, that the Pre-Cambrian granite has been reached. At Tomah the granite is reached at depth of 400 feet; at Sparta, about 425 feet; and at Oil City, at 490 feet. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Monroe County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Lower Magnesian limestone	0 to 150
Upper Cambrian (Potsdam) sandstone	200 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The chief water-bearing horizons are the Potsdam sandstone in the upland areas and the alluvial sand and gravel in the valley bottom areas. The limestone is a source of supply on the uplands south of Tomah and Sparta.

South of Tomah, on the Lower Magnesian limestone ridge, most wells are from 100 to 300 feet in depth. Some of the wells, those less than 100 feet deep, get their supply from within the limestone. A few shallow wells get their supply from loess clay over the limestone, but the quantity of water from this source is very limited. Near the contact of the Lower Magnesian limestone and underlying sandstone, are many fine springs.

FLOWING WELLS

An interesting area of flowing wells is found at Sparta and vicinity, including Angelo, Trout Falls, Farmers Valley, Leon, Rockland, and Melvina. The first of these wells was sunk as an experiment at Sparta in 1867. The area of flowing wells extends from Rockland up the La Crosse river to Trout Falls, and up Little La Crosse river as far as Melvina. It also extends up the various tributaries of these streams for a considerable distance. Small artesian areas are scattered along

the rivers in the townships of Leon, Adrian, Sparta, Angelo, and Lafayette. The flows are strong and the water is good, although some of it contains considerable iron. Between 200 and 300 flowing wells have been drilled in Sparta and vicinity.

In the city of Sparta and the village of Angelo, are nearly 100 flowing wells. Many of them have stopped flowing, some because other wells at lower levels lowered their head, others on account of leakage because the pipes have rusted, and some because the water escapes between the pipe and the shale. One of the best wells was put down in 1872 on Milo Babcock's property, in the vilage of Angelo. This well seems to affect several in this vicinity. When the pipe was rusted off the well ceased flowing until new casing could be put in. During this time a number of wells not far distant started flowing or increased their flow but decreased again as soon as the casing was inserted in the old well and allowed free flow. The well drillers at Sparta claim that at Sparta, Leon, Rockland, and as far north as Trout Falls, they usually pass through two beds of shale, but in some places only one bed of shale, in drilling deep wells. In the city of Sparta the first shale bed is struck at about 250 feet. Its thickness is from 2 to 10 feet, while the lower shale bed is struck at about 300 to 310 feet, and varies in thickness from 12 to 15 feet. There are no samples or logs of wells available. Artesian flows have been obtained between these shale beds, below the second shale bed, and in a few cases before striking any bed of shale or clay. Northward a shale or clay bed comes nearer the surface, and in the vicinity of Trout Falls the upper shale bed lies at a depth of only 80 or 90 feet. At Hanchett's farm, about half way between the Falls and Sparta, the shale is 175 feet below the surface. Artesian wells are obtained all the way up the valley. Their depths are usually between 260 and 800 feet. The water in the artesian wells in the vicinity of Sparta and Angelo rises to an elevation of about 798 feet above sea level. At Leon, where the valley is wide and the limestone ridges are far back from the river, the head, as shown by Mr. George Kidney's well is 796 feet above sea level. Farther up the valley near Melvina a well was drilled on John Steele's farm to a depth of 260 feet with head of 806 feet or 11 feet above the surface. Farther up the river the heads are still higher.

Log of well of John Steele, Melvina.

Formation.	Thickness.
	Feet.
Clay	17
Soil, sand	15
Upper Cambrian (Potsdam) sandstone	244
Blue clay and shale	1
Total depth	277

The following record, with the one of Mr. Steele's well at Melvina, will explain the general sections in the vicinity of Sparta, and Angelo. It should be remembered, however, that many of the wells also penetrate the second shale bed and get their flow from the sandstone below it. The casing, however, seldom extends below the first rock, thus offering much freedom to the waters in selecting their upward paths.

Log of well of Judge McCoy, Sparta.

Formation.	Thickness.
	Feet.
Alluvium	60
Upper Cambrian (Potsdam).	
Sandstone	110
Shale	40
Sandstone	40
Total depth	250

A comparison of these two records with the reports of the drillers regarding the shale beds at Sparta indicate that there is a marked irregularity in thickness and depth of the shale. The McCoy well is 6 miles east and the Babcock well about 3 miles east of Sparta. However, this shale bed may be present at Sparta, and not always reported. Before the structural relations of the clay or shale beds can be definitely worked out it is necessary to obtain more accurate logs of the wells in various parts of the slope than are now at hand.

The head is highest at the upper end of the valley. The head decreases down the valley in the same manner as in the Kickapoo and Baraboo river valleys. Flows need not be looked for on any of the streams, unless it be on the lowlands or plains along the river valleys. The nearest wells in the vicinity will offer much information along this line. There are many places along these streams where much stronger flows can be obtained than any thus far struck.

Wherever a shale or clay bed is passed through and a flow obtained beneath it the casing should be extended into the shale or clay bed and a firm contact made, if the best and most permanent flows are desired. If this precaution is neglected much of the water necessarily escapes into the porous sandstone above the clay bed and fails to rise to the surface and sooner or later the flow may cease entirely.

A little more expensive method, but one that will well repay the investment made, is to drill the well a few inches larger in diameter down to the clay or impervious shale and drive the casing down into this for a short distance, then decrease the drill hole and insert a new casing inside of the outer one and extend it through the impervious bed to the water bearing horizon. A filling with Portland cement, for a few feet between the two pipes prevents all escape between the rock and casing and shuts out all lateral escape into the overlying sandstone and the inner tubing can easily be repaired. If this precaution had been taken for all the flowing wells at Sparta and vicinity many of the wells would not need to be pumped and the artesian basin would today be much stronger. Another precaution that ought to be insisted upon is that wells on lower ground reduce their flow to a minimum so as not to interfere unduly with their neighbors flows on higher ground.

The area of flowing wells about Sparta extends down the La Crosse river only to the vicinity of Rockland. Farther down the valley, at Bangor and West Salem, in La Crosse county, no flowing wells occur. Various reasons have been given for the absence of favorable conditions in this portion of the valley, but the probable explanation appears to be that given in the general description of the artesian wells in La Crosse valley, on pages 67–9.

The Kickapoo Valley has many features in common with the La Crosse and the Baraboo valleys. The Kickapoo river flows throughout its entire extent in the Upper Cambrian (Potsdam) sandstone and is bordered on both sides by bluffs capped with limestone. The groundwater in the bluffs is a controlling factor in the development of the high heads noted in the flowing wells in this valley. Flowing wells may be obtained on low ground nearly all the way down the valley to Wauzeka, where the Kickapoo enters the Wisconsin river.

At Wilton, near the head of the Kickapoo valley, is the highest artesian head found anywhere within Wisconsin in wells whose waters rise and flow from the Potsdam sandstone. The artesian water at Wilton rises to an elevation of 980 feet above tide.

On going down the Kickapoo valley the head decreases as in the Baraboo valley, and at Wauzeka, it is only 687 feet above tide.

Flowing wells about Wilton, with heads of 980 feet above tide, are owned by A. J. Dix, Rudolph Green, Willie Arndt, J. E. Egan, and others. They are all 6-inch wells and were flowing strongly in 1905, nearly filling the 6-inch pipes.

At Oil City was drilled the first artesian well in the Kickapoo valley by oil prospectors from Sparta.

Section of well drilled in 1866 at Oil City.

Formation	Thickness.	Remarks.
	Feet.	
Sand and clay	10	
Gravel	12	
Quicksand	20	
Sandstone, soft (cased)	30	
Sandstone, compact	228	At 90 ft. the water rose 5 ft. above surface.
Open crevice, main water flow	4	
Sandstone, hard and compact	186	
"Granite"	20	
Total depth	510	The water rises 25 ft. above surface. 920 ft. A. T.

WATER SUPPLIES FOR CITIES AND VILLAGES

Sparta.—The population of Sparta is 3,973. It is located on sandy, alluvial bottoms lands in the valley of the La Crosse river. The city has a water supply and sewage system. The water supply is derived mainly from two groundwater wells,[1] and to a small extent from two artesian wells, which are 6 inches in diameter and 200 feet deep. One of the groundwater wells is 12 feet in diameter by 20 feet deep, and the other, 31 feet in diameter and 23 feet deep. The open groundwater wells yield most of the supply. The average daily pumpage is 298,000 gallons per day. The supply from the smaller of the two wells can be exhausted by about four hours pumping.

The sewage, without treatment, empties into the La Crosse river. About 50 per cent of the houses have water connections, and 20 per cent are on the sewage system. About 30 per cent of the houses have cess pools.

Tomah.—This city, having a population of 3,419, is situated on the broad sandy plain bordering the south fork of the Lemonweir river. The city has water supply and sewage systems. The water supply is derived from two 8-inch wells 172 and 150 feet deep cased 40 feet. The

[1] Kirchoffer, W. G. Bulletin, Univ. Wis. No. 106, p. 221.

Mineral analyses of water in Milwaukee County—**Continued.**

	Lake Michigan.					Springs.	
	22.	23.	24.	25.	26.	27.	28.
Silica (SiO_2)	6.6	5.6	....	....	....	11.78	16.0
Aluminum and iron oxides $Al_2O_3+Fe_2O_3$)	1.6	1.9	1.5	4.5	undt.	1.32	5.0
Calcium (Ca)	33.6	26.6	31.6	34.0	31.8	74.72	70.4
Magnesium (Mg)	11.9	11.3	10.5	11.2	10.6	28.12	32.0
Sodium and potassium (Na+K)	2.2	6.1	3.4	4.8	6.7	3.75	11.3
Carbonate radical (CO_3)	66.7	68.0	70.2	76.6	71.0	174.83	167.4
Sulphate radical (SO_4)	21.6	8.0	6.9	8.1	9.0	15.46	12.8
Chlorine (Cl)	3.5	3.5	2.9	3.1	7.2	3.04	2.4
Organic matter	Trace.	1.0	....	....	....	....	....
Total dissolved solids	148.0	131.0	127.0	142.3	136.3	313.07	317.3

	Springs.						Creek and surface well.
	29.	30	31.	32.	33.	34.	35.
Silica (SiO_2)	35.0	12.4	13.7	123.0	10.0	10.4	....
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)	3.6	2.0	2.9	188.0	....	3.4	7.0
Calcium (Ca)	82.0	83.4	66.8	163.6	90.0	133.5	41.8
Magnesium (Mg)	44.3	36.3	32.2	52.9	38.8	64.5	37.4
Sodium and potassium (Na+K)	8.7	11.1	9.0	1,452.7	29.5	51.0	24.3
Carbonate radical (CO_3)	236.0	178.6	180.3	447.4	241.0	268.1	60.9
Sulphate radical (SO_4)	6.8	58.1	5.4	185.5	33.7	209.6	180.8
Chlorine (Cl)	2.4	17.1	9.9	2,080.0	9.6	31.6	14.3
Total dissolved solids	418.8	399.0	320.2	4,643.1	452.6	772.1	366.5

22. Lake Michigan. City water supply of South Milwaukee. Analyst, Dearborn Drug & Chemical Co., March 5, 1912.
23. Lake Michigan. Direct from city mains, Milwaukee. Analyst, Dearborn Drug & Chem. Co., Sept. 6, 1907.
24. Lake Michigan. City supply for Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July, 1889.
25. Lake Michigan. City supply for W. Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Dec. 15, 1894.
26. Lake Michigan, Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 13, 1907.
27. Elim Spring, 1½ miles west of Brown Deer. Analyst, A. S. Mitchell, Aug. 4, 1896.
28. Hacketts Spring, Hales Corners. Analyst, G. Bode. Geology of Wisconsin, Vol. 2, p. 32, 1877.
29. Schweickardt's Spring, Wauwautosa. Analyst, G. Bode. Geology of Wisconsin, p. 32, vol. 2, 1877.
30. Nee-ska-ra Spring, Wauwatosa. Analyst, Frank Kramer, Jan., 1912.
31. Nee-ska-ra Spring, Wauwautosa. Analyst, J. H. Long.
32. Eureka Spring, Milwaukee. Analyst, G. Bode. Geology of Wisconsin, vol. 2, p. 31, 1877.
33. Siloam Spring, Milwaukee. Analyst, G. Bode. Geology of Wisconsin, vol. 2, p. 31, 1877.
34. Spring near C. & N. W. R. Pass. Depot, Milwaukee. Analyst, G. M. Davidson, July 16, 1898.
35. Creek and Well at North Milwaukee, C. M. & St. P. Ry. Co. Analyst, G. N. Prentiss, July 9th, 1897.

***Mineral analyses of water in Milwaukee County*—Continued.**

	Creek and surface well.		Surface deposits.				
	36.	37.	38.	39.	40.	41.	42.
Depth of well......... feet..	....	....	28	24	24	30	42
Silica (SiO_2)...............	....	....	....	11.9	undt..	....	....
Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$)............	3.8	undt.	2.7	1.0	....	1.5	5.1
Calcium (Ca)	49.1	54.9	53.6	151.3	66.6	72.4	57.6
Magnesium (Mg)............	27.4	27.7	24.0	53.4	39.0	38.1	35.4
Sodium, and potassium (Na+K)....	48.5	55.5	46.5	116.4	33.3	30.4	32.3
Carbonate radical (CO_3).. .	87.5	94.9	87.6	343.7	150.4	168.4	148.2
Sulphate radical (SO_4)......	167.1	204.8	174.0	146.5	143.5	109.0	106.0
Chlorine (Cl)...............	6.5	undt.	3.5	87.8	undt.	6.2	6.7
Total dissolved solids.......	384.9	437.8	391.9	912.0	432.8	426.0	386.3

	Surface deposits.		Niagara limestone.				
	43.	44.	45.	46.	47.	48.	49.
Depth of well .... feet..	....	28	66	130	140	73	52
Silica (SiO_2)...........	12.50	....	....	28.4	....	....	....
Aluminum and iron oxides $Al_2O_3+Fe_2O_3$).....	1.54	2.7	....	....	....	2.6	1.4
Calcium (Ca)...............	93.50	53.6	36.6	55.5	155.6	66.5	52.4
Magnesium (Mg)...........	53.84	24.0	36.4	36.3	49.8	36.9	24.5
Sodium and potassium (Na+K)..................	4.99	46.5	29.6	15.3	6.9	34.0	43.1
Carbonate radical (CO_3)....	228.94	87.6	129.0	172.8	173.7	148.5	85.6
Sulphate radical (SO_4)......	78.07	174.0	17.3	22.5	295.8	132.4	169.0
Chlorine (Cl)...............	7.71	8.5	32.8	2 6	7.0	3.7	4.3
Organic matter..	36.49	....	....	....	....	....	....
Total dissolved solids...	483.09	391.9	281.7	333.4	688.8	424.6	380.3

36. Creek and well at North Milwaukee, C. M. & St. P. Ry. Co. Analyst, G. N. Prentiss, July 23, 1897.
37. Creek and well at North Milwaukee, C. M. & St. P. Ry. Co. Analyst, G. N. Prentiss, Feb. 12, 1899.
38. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July 8, 1889.
39. Well of C. & N. W. Ry. Co. at Granville. Analyst, G. M. Davidson, July 23, 1897.
40. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, G. N. Prentiss, Feb. 5, 1900
41. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, G. N. Prentiss, Dec. 19, 1894.
42. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, G. N. Prentiss, May 2, 1898.
43. Well of C. & N. W. Ry. Co., Coal Chute, Butler. Analyst, G. M. Davidson, Nov. 3, 1911.
44. Well of C. M. & St. P. Ry. Co., North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., July 8, 1889.
45. Well of E. P. Allis, Milwaukee. Analyst, McLaren.
46. Well of Plankington, Milwaukee. Analyst, D. Fisher.
47. Well of C. M. & St. P. Ry. Co. at Granville. Analyst, Chemist, C. M. & St. P. Ry. Co., July 6, 1889.
48. Well of C. M. & St. P. Ry. Co., Oakwood. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 17, 1890.
49. Well of Mr. Poppert, North Milwaukee. Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 12, 1899.

Mineral analyses of water in Monroe County.—Continued.

	Creeks and Rivers.				Spring.	Surface deposits.		
	9.	10.	11.	12.	13.	14.	15.	16.
Depth of well........ .... feet..	....	....	....	....	....	12	30	16
Silica (SiO_2).............				13.5		5.5	9.0	7.1
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	3.6	Undt.	8.6	1.3	5.0	1.0	2.5	1.2
Calcium (Ca)......................	28.2	11.8	29.1	20.5	10.5	14.6	23.2	7 7
Magnesium (Mg)................	14.8	5.1	12.7	10.2	4.3	0.7	10.3	1.7
Sodium and Potassium (Na+K)	5.1	6.4	4.2	1.9	2.8	1.5	3.9	1.8
Carbonate radicle (CO_3)........	78.8	24 4	54.0	51.7	26.8	21.4	55.2	4.7
Sulphate radicle (SO_4)	9.2	2.24	30.6	8.0	3.5	3.6	12.0	17.9
Chlorine (Cl).......	1.1	Undt.	1.8	2.0	1.8	2.6	3.4	2.8
Total dissolved solids).......	141.	70.	150.	109.	55.	51.	120.	45.

	Surface deposits.							Upper Cambrian (Potsdam) sandstone.	
	17.	18.	19.	20.	21.	22.	28.	24.	25.
Depth of well..... feet..	20	74	70	28	20	20	?	185	340
Silica (SiO_2)			11.4	14.0				11.8	18.6
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)...	3.6	2.9	1.8	1.5	[1]53.8	4.6	1.9	28.7	17.4
Calcium (Ca)............	11.1	7.2	25.9	24.1	17.6	47.2	22.1	13.9	38.7
Magnesium (Mg).........	5.6	3.0	6.6	14.1	1.4	16.9	6.8	5.9	19.6
Sodium and Potassium (Na+K)	3.5	14.6	3.9	3.8	8.1	8.7	21.3	2.7	4.9
Carbonate radicle (CO_3)	30.5	23.3	50.4	68.9	18.0	29.8	29.5	23.3	96.3
Sulphate radicle (SO_4)..	6.0	2.3	7.8	3.5	25.8	145.9	30.0	17.1	16.3
Chlorine (Cl)...	0.9	14.9	6.0	5.9	7.4	2.6	27.0	4.2	7.5
Total dissolved solids	61.	68.	114.	136.	182.	256.	148.	108.	219.

9. Council Creek at proposed intake for city water works, Tomah. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 12, 1894.
10. Council Creek, City Water Works, Tomah. Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 6, 1900.
11. Council Creek and well, Tomah. Analyst, Chemist, C. M. & St. P. Ry. Co., May 20, 1893.
12. North Branch, Lemonweir River near Wyeville. Analyst, G. M. Davidson, Dec. 9, 1910.
13. Spring at Tunnel City. Analyst, Chemist C. M. & St. P. Ry. Co., April 5, 1899.
14. Well of C. & N. W. Ry. Co., Wyeville. Analyst, G. M. Davidson, Dec. 16, 1910.
15. Well, Sparta. Analyst, Dearborn Drug & Chem. Co., June 1, 1900.
16. Well at Contractor's Camp, ½ mile west of McCoy. Analyst, G. M. Davidson, Dec. 20, 1910.
17. Well of C. M. & St. P. Ry. Co., Tomah. Analyst, Chemist, C. M. & St. P. Ry. Co., June 8, 1901.
18. Well of C. M. & St. P. Ry. Co., Tomah. Analyst, Chemist C. M. & St. P. Ry. Co., June 23, 1893
19. Well at Robert McMullen's farm near C. & N. W. Ry. Co. station, Tomah. Analyst, G. M. Davidson, Oct. 3, 1910.
20. Well of C. & N. W. Ry. Co., 1500 feet south of station at Kendall. Analyst, G. M. Davidson, Nov. 28, 1896.
21. Well of C. M. & St. P. Ry. bridge shop, Tomah. Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 17, 1890.
22. Well of C. M. & St. P. Ry. Bridge Shop, Tomah. Analyst, Chemist, C. M. & St. P. Ry. Co., June 14, 1892.
23. Well of C. M. & St. P. Ry. Bridge Shop, Tomah. Analyst, Chemist C. M. & St. P. Ry. Co., May 18, 1893.
24. Well of Winston Bros., Contractors, 1500 feet west of C. & N. W. Station, Tunnel City. Analyst, G. M. Davidson, Dec. 9, 1910.
25. Well of C. & N. W. Ry. Co., Kendall. Analyst, G. M. Davidson, Mar. 12, 1902.

[1] No. 21. Oxides a little high. There is some clay in it but no figures given.

Mineral Analyses of Water in Monroe County—Continued.

	Upper Cambrian (Potsdam) sandstone.							
	26.	27.	28.	29.	30.	31.	32.	33.
Depth of well............ feet..	240	262	200	300	....	307	....	....
Silica (SiO_2)........................	15.9	7.7	1.0	9.9	18.			
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)................	1.3	5.5	8.5	....	5.	5.0	4.3	11.5
Iron (Fe).......	....	....	....	3.1	....	....	....	....
Calcium (Ca)..................	11.7	9.0	36.2	31.3	30.5	45.7	25.6	43.9
Magnesium (Mg)..................	5.2	3.6	18.6	8.6	10.8	20.6	15.6	20.6
Sodium and Potassium (Na+K)	1.6	1.4	15.6	3.9	3.7	4.6	10.2	7.8
Carbonate radicle (CO_3).	20.3	18.5	76.3	49.	50.3	111.2	70.8	115.3
Sulphate radicle (SO_4)...........	16.1	6.3	20.0	31.7	32.6	15.9	21.4	17.5
Chlorine (Cl)......................	2.5	2.1	19.7	12.3	7.	4.3	7.	0.7
Organic matter	....	18.2	....	....	....	....	....	....
Total dissolved solids............	75.	54.	196.	151.	158.	207.	155.	217.

26. Well of U. S. Government, Camp McCoy. Analyst, G. M. Davidson, Jan. 4, 1911.
27. Well of C. & N. W. Ry. Co., McCoy. Analyst, G. M. Davidson, Jan. 22, 1912.
28. Well of City Water works, Sparta.
29. Private well, Sparta. Analyst, G. Bode.
30. Court House well, Sparta. Analyst, G. Bode, Geol. of Wis., vol. 2, p. 32, 1877.
31. Well of C. M. & St. P. Ry. Co., Sparta. Analyst, Chemist C. M. & St. P., Aug. 1888.
32. Well of City Water works, Sparta. Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 20, 1895.
33. Artesian well Sparta near Winship house, Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 29, 1903.

OCONTO COUNTY

Oconto county, located in the northeastern part of the state on Green Bay, has an area of 1,080 square miles and a population of 25,657. About 39.8 per cent of the county is in farms, of which 47 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is quite gently undulating, with somewhat broken and hilly areas in the northwestern part. The land slopes to the southeast towards Green Bay. The most prominent relief in the county is the range of quartzite hills east of Lakewood extending into Marinette county, which reach 300 or 400 feet above the surrounding area and attain an elevation of 1,600 to 1,700 feet above sea level. The prevailing altitude of the northwestern part of the county is 1,200 to 1,600 feet, gradually falling to 800 and 600 feet for a large portion of the southeastern part. Oconto river drains the principal part of the county. This river has a fall of 756 feet in the distance of 54 miles between Wabeno, a short distance north of the county, and Underhill,

and a fall of 190 feet in its lower course of 33 miles between Underhill and its mouth at Oconto.

GEOLOGICAL FORMATIONS

The geological formations are essentially the same as those of Marinette county, the northwestern part of the county showing the outcrop of Pre-Cambrian crystalline rocks, and the southeastern part the overlying formations of Upper Cambrian (Potsdam) sandstone, Lower Magnesian limestone, St. Peter sandstone and the Galena-Platteville (Trenton) limestone. The soils are largely loams and sandy loams with the usual areas of wet and swamp lands characteristic of recent glaciated drift districts. A strip of sandy loam soils 8 to 12 miles wide extends northeast and southwest through the central part of the county along the outcrop of Potsdam sandstone (See map, Pl. I). Glacial drift and alluvial sand are abundant surface deposits. A belt of hummocky terminal moraine extends northeast through the vicinity of Gillett.

The cross section, extending northwest-southeast through the county,

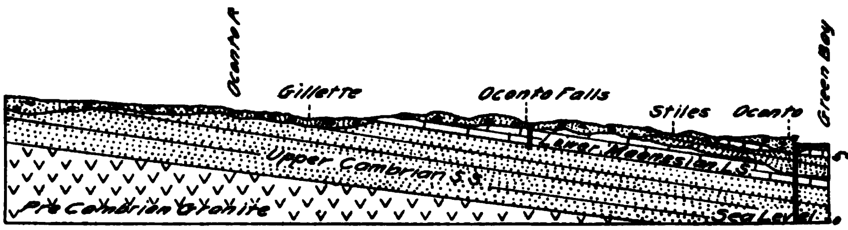

Fig. 54.—Geologic section, east-west, across southern Oconto County.

(Fig. 54), illustrates the relations of the geological formations and shows the position of the chief water-bearing horizons.

In many wells drilled within the area of the Trenton limestone no marked division of strata is noted below the St. Peter sandstone. Some wells pass through sandstone throughout, thus making it almost impossible to separate by the drillings the St. Peter, the Lower Magnesian and the Potsdam formations.

The thickness of the surface formations of alluvial and glacial deposits is variable between wide limits, as in other parts of the state. In the old pre-glacial valleys, river deposits have accumulated to a depth of over 300 feet, as illustrated by the railroad well at Northern Junction. Outside of the old valleys, however, the glacial and alluvial deposits are usually less than 100 feet thick.

The thickness of the hard rock formations is also variable on account of the great diversity in amount of erosion. The Pre-Cambrian granite floor of relatively impervious rock lies immediately under the surface formation in the northwestern part of the county and is within striking distance in moderately deep wells in the southeastern part.

The Upper Cambrian (Potsdam) sandstone in Oconto county, and adjoining counties, is not so thick a formation as it is in the southeastern and southern parts of the state. The combined thickness of the St. Peter and Lower Magnesian formations is also probably less in the northeastern part of the state than elsewhere. The complete thickness of the Trenton formation is probably not present anywhere within the area of its outcrop within the county.

The approximate range in thickness of the formations in the county may be summarized as follows:

Approximate range in thickness of formations in Oconto County.

Formations.	Thickness.
	Feet.
Surface formation	0 to 350
Galena-Platteville (Trenton) limestone	0 to 200
St. Peter and Lower Magnesian formations	0 to 150
Upper Cambrian (Potsdam) sandstone	0 to 500
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The chief water-bearing formations are the surface deposits of drift and stratified sands and gravels, and the formations of Upper Cambrian sandstone and St. Peter sandstone. The Lower Magnesian is also an important source of supply. The Galena-Platteville (Trenton) limestone contains only a small amount of water and is usually drawn upon only in shallow wells within its area of outcrop.

In the northwestern part of the county within the general area of the crystalline and granite rocks, the surface deposit of drift is the important source of supply. Wells in the crystalline rock are also common, the supply being obtained from open fractures and fissures.

In the southeastern part of the county abundant water can be obtained from the sandstone formations, as well as from the surface deposits of drift and alluvium.

The general water level is usually not far below the surface. Few common wells on the uplands are over 100 to 200 feet in depth, a

sufficient supply being generally obtained at less than 100 feet. In the valleys the water level stands near the surface and wells are usually only from 10 to 40 feet deep.

FLOWING WELLS

Flowing wells confined to the southeastern part of the county, are obtained mainly from the rock formations, although in some important instances at least, as at Stiles, the favorable conditions for the development of the artesian flows are due to the impervious character of the surface deposits of clay and drift overlying the rock formations.

The water in the sandstone beds underlying the Trenton limestone is very generally under strong pressure and in low ground, as at Oconto, Abrams, Brookside and Little Suamico, rises some distance above the surface. At Lena and Hickory, however, the artesian head stands a few feet below the surface.

At Abrams and Little Suamico flowing wells are obtained from several horizons, from within the Lower Magnesian limestone, at the contact of the Trenton and Lower Magnesian above, and at the contact with the St. Peter sandstone below, and from within the Upper Cambrian sandstone. The strongest and best flows are obtained from the Upper Cambrian sandstone at a depth of about 300 feet. The heads as now observed are very irregular, for the packing in some of the wells is no longer in place, and the water escapes into the crevices and fissures of the upper horizon of the Trenton limestone. To get good flows at the surface it is necessary, therefore, to pack the wells at a point somewhere below the Trenton limestone. Usually the packing is placed between 60 and 100 feet below the surface. It has been observed that wells drilled east or southeast of older wells affect the flow perceptibly, and in some cases have stopped their flow, although the later wells were put down as much as two miles or more to the southeast, while those wells drilled to the north or northeast do not have this effect, clearly showing that the pressure comes from a north west direction. The great variation in head, as shown by these wells, and others along the Green Bay shore, both north and south, are due, not so much to a deficient supply of water as to leakage in the well or to a neighboring well which draws down the water.

WATER SUPPLIES FOR CITIES AND VILLAGES

Oconto. The city of Oconto on Oconto river, about two miles from its outlet into Green Bay, has a population of 5,629. The city water supply, furnished by a private company, is obtained from three 6-inch artesian wells, 309, 318 and 596 feet deep, cased 40 feet to rock. (Also reported as obtained from six wells). These wells flow at the surface, elevation of curb being 590 A. T. The 596 foot well checked the flow from the other two wells and furnishes about half the supply. The city supply is connected with the Oconto river through one intake, used probably only in case of emergency. The average daily pumpage is about 445,000 gallons. About 60 per cent of the houses are connected with the water supply, and about 40 per cent, with the sewage system. The sewage is emptied, without treatment, into the river.

Information concerning the strata passed through in the city wells is rather indefinite. The thickness of the Trenton limestone is usually between 80 and 140 feet. Below this limestone is a white coarse sandstone, which resembles the St. Peter sandstone, and is from 12 to 30 feet thick. This sandstone furnishes the supply for a number of wells, although similar flows are obtained in the Trenton limestone.

Oconto Falls. The population of Oconto Falls is 1,427. The city water supply is obtained from a well 187 feet deep. The average daily pumpage is 30,000 gallons. About 30 per cent of the houses are connected with the system. Private wells are usually 15 to 30 feet deep. Some wells are drilled deeper. The well of the Oconto Falls Mfg. Co. is 270 feet deep, formation not reported.

Stiles. The wells at Stiles, population about 500, are for the most part very shallow. The water is obtained from the upper horizon of the Lower Magnesian limestone. Mr. Scherer of Oconto, who drilled most of the flowing wells in Stiles, states that in each case the surface sands were underlain by bowlder clay which was very difficult to drill, below this was a pure red clay, easily bored, and this was underlain by limestone which gave a flow which was weak at first, but which increased on going deeper into the limestone. Water comes from crevices in the rock and subsequent drilling over 200 feet in Potsdam sandstone did not increase the flow.

Lena and Hickory. At Lena a well passed through 91 feet of Lower Magnesian limestone, while at Hickory a well was put down 330 feet all the way in sandstone after passing through the drift. These wells are artesian, although the water stands a few feet below the sur-

face. Water under pressure is obtained from all the formations, the Trenton, the St. Peter, the Lower Magnesian and the upper Cambrian, and often 3 to 5 different sources of supply in the same well are struck.

Northern Junction. At Northern Junction an unsuccessful attempt was made by the Chicago and Northwestern Railroad Company to secure a water supply sufficient for use of its locomotives, by drilling a deep well. The strata encountered during the drilling was as follows:

Log of C. & N. W. Rw. Well at Northern Junction.

Formation.	Thickness.
	Feet.
Sand	75
Clay	18
Shale rock	2
Quicksand	78
Clay	2
Quicksand	3
Clay	107
Quicksand	5
Clay	11
Quicksand, to bottom of drilled hole	19
Total	320

QUALITY OF THE WATER

The mineral analyses of some of the waters of Oconto county are shown in the following table. The waters of the creeks, rivers and lakes, as well as that from the surface deposits, is of low mineral content, though somewhat too high in mineral to be classed as soft water. The waters from the limestone area, as at Oconto, in both springs and deep wells reaching through the limestone to the St. Peter and the Potsdam, are of moderate mineral content and distinctly hard waters. In general, the water supplies from the northwestern part of the county are likely to possess a much lower degree of hardness than the waters from the limestone district of the southern part of the county.

The water from the Oconto river at Oconto, No. 3, contains 0.98 pounds of incrusting solids in 1,000 gallons, while that from the artesian wells, furnishing the city water supply, No. 7, contains 1.52 pounds in 1,000 gallons.

Mineral analyses of water in Oconto County.

(Analyses in parts per million)

	Creeks and Rivers.			Lake.	Spring.	Surface deposits.	St. Peter and Upper Cambrian sandstone.	
	1.	2.	3.	4.	5.	6.	7.	8.
Depth of well............ feet..	....	....	....	....	....	16	309–596	309–596
Silica (SiO_2)........................	9.9	5.8	7.8	6.4	16.8	8.0	6.6	6.9
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)................	0.5	0.6	0.3	0.5	....	....	1.5	1.6
Aluminium oxide (Al_2O_3)......	....	....	....	....	2.7	....	....	....
Iron (Fe)........................	....	....	....	....	0.1	....	....	....
Calcium (Ca)....................	31.3	30.5	26.0	28.1	64.5	36.6	31.7	39.2
Magnesium (Mg)..................	14.3	15.0	10.5	19.1	27.2	13.9	19.1	18.5
Sodium (Na) Potassium (K)................	3.2	1.0	6.4	0.9	8.6 1.2	4.7	32.3	20.5
Carbonate radicle (CO_3)........	75.3	82.0	52.1	89.3	163.7	93.3	65.0	61.8
Sulphate radicle (SO_4)..........	1.7	1.3	20.7	....	14.8	2.5	66.9	68.7
Chlorine (Cl)....................	4.8	1.6	9.8	1.4	4.0	0.9	28.1	31.5
Organic matter..................	....	15.0	18.6	28.2	....	....	....	....
Total dissolved solids...	141.	138.	134.	146.	304.	160.	251.	249.

1. Creek at Kingston, Analyst, G. M. Davidson, C. & N. W. Ry. Co., Aug. 1897.
2. McCassling's brook, 1½ miles N. of Lakewood, Analyst, G. M. Davidson, C. & N. W. Ry. Co., Mar. 31, 1908.
3. Oconto river at Oconto, Analyst, G. M. Davidson, June 1892.
4. Lake at Gillette, Analyst, G. M. Davidson, C. & N. W. Ry. Co., Sept. 30, 1902.
5. Arbutus Mineral Spring at Oconto, Analyst, A. S. Mitchell, Aug. 1898.
6. Railroad well at Oconto Junction, Analyst, Chemist, C. M. & St. P. Ry. Co., July 13, 1891.
7. Artesian wells of City Water Works at Oconto, 3 wells, 309, 318 and 596 ft. deep, Analyst, G. M. Davidson, June 1892.
8. City Water Supply, Oconto, Analyst, Dearborn Drug & Chem. Co., Feb. 26, 1903.

ONEIDA COUNTY

Oneida county, located in the northeastern part of the state, has an area of 900 square miles, and a population of 11,433. About 13.6 per cent of the county is in farms, of which 22.7 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is a gently undulating plain, dotted with numerous lakes and swamps. In the northeastern part are some relatively prominent drift hills. The county is drained by the Wisconsin River and its tributaries. The soil varies from a fine sand to sandy loam and loam. The elevation is very generally between 1,500 and

1,700 feet above sea level, most of the land being very little higher than the level of the lakes and streams.

GEOLOGICAL FORMATIONS

The geological formations are the surface formations of glacial drift and associated sand and gravel plains, and the underlying granitic formation. The surface formation, very generally, covers the granite rock, the latter being exposed only rarely along the river bottoms. The drift is of variable thickness, but is usually from 50 to 200 feet thick. For geologic section, see Fig. 23.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizon is the surface formation of drift, in which an abundant supply can generally be obtained at relatively shallow depths. The water level is very generally near the surface throughout the county.

WATER SUPPLIES FOR CITIES AND VILLAGES

Rhinelander. Rhinelander, the county seat, located on the site of extensive water power on the Wisconsin river, has a population of 5,637. Its elevation is 1,550 feet above sea level.

Until recently the city supply was obtained directly from the Wisconsin river, and at times the water was highly colored and full of organic matter. At present the supply is obtained from a large shallow well, 30 feet in diameter and 20 feet deep, located beside the river, the well being supplied with a number of well points leading from the bottom of the well to the bed of the river which discharge into the well when the water is drawn down. The present supply is mainly river water and contains much organic matter. The average daily pumpage is about 989,000 gallons. A large per cent of the houses are connected with the water supply. The city sewage is emptied without purification into the river. The private wells are generally shallow, from 20 to 50 feet deep.

Minocqua. Minocqua, situated on Lake Kawaquesagon, has an estimated population of 750. The elevation is 1,603 feet. The underlying formation is a sandy drift. A public water supply system has been installed, the supply being obtained from a 172-foot well, in the drift, and from the lake at a depth of 20 feet, 300 feet from the shore. The daily consumption of water is 25,000 gallons. About 25 per cent of the houses connect with the city supply. The private wells are relatively

shallow, generally from 15 to 25 feet deep. The sewage is emptied into the lake.

QUALITY OF THE WATER

The mineral analyses of water in Oneida county shows the water to be soft and hard water. Soft water of relatively low mineral content is likely to occur throughout the county in all the lakes, streams, and in the surface deposits. There are, however, exceptions to this general rule as indicated in the table of analyses. The content of organic matter in the city water supply at Rhinelander, as shown by the the analysis, No. 6, indicates that the supply is largely drawn from the river, or that the ground water source is contaminated. The water of the railroad well at Pelican is largely from a ground water source, rather than from the lake, though this was not intended when the reservoir well was constructed. When the pump is not working a constant stream goes through the pipe from the reservoir into the lake. The water from the Pelican railroad well No. 5 and that from the creek at Monico Jct. are unusually hard waters in this locality.

The city water supply of Rhinelander contains 0.55 pounds of incrusting solids in 1,000 gallons while that from the railroad well at Pelican contains 1.55 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Oneida County.

(Analyses in parts per million)

	Creek.	Lake.			Spring.	Surface Deposits.		
	1.	2.	3.	4.	5.	6.	7.	8.
Depth of well .... feet	......	......	......	......	......	20	20	120
Silica (SiO_2)	18.6	4.0	22.9	......	7.5	18.3	8.7	5.3
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	3.7	1.7	8.5	2.6	......	0.8	1.0	
Calcium (Ca)	34.5	8.0	4.5	12.6	6.4	43.8	16.9	9.7
Magnesium (Mg)	14.3	0.8	2.2	3.4	1.6	17.4	4.1	3.6
Sodium (Na) Potassium (K)	4.4	4.7	4.5 4.5	4.8	13.1	5.4	1.7	10.3
Carbonate radicle (CO_3)	60.7	4.7	11.6	31.9	19.5	92.5	35.7	22.1
Sulphate radicle (SO_4)	41.5	24.9	8.2	1.3	15.8	15.7	......	19.5
Chlorine (Cl)	6.8	......	5.6	0.7	1.6	6.7	2.7	3.1
Organic matter	27.0	11.3	......	......	......	......	28.6	......
Total dissolved solids	185.	49.	72.	57.	66.	201.	71.	74.

1. Creek, Monico Junction, Analyst, G. M. Davidson, July 24, 1909.
2. Small Lake near Worden, eight miles from Pratt Junction, Analyst, G. M. Davidson, July 17, 1909.
3. Two Sisters Lake, sample taken at 62.1 ft. (19 m.) Analysts, E. B. Hall and C. Juday, Aug. 27, 1907, Wis. Survey Bull. 22, p. 170.
4. Minocqua Lake, Minocqua, Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 18, 1892.
5. Cassian Spring, Cassian, Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 15, 1897.
6. Reservoir and Lake at Pelican, Analyst, G. M. Davidson, July 17, 1909.
7. Well of City Water Works, Rhinelander, Analyst, G. M. Davidson, Aug. 26, 1909.
8. Well of C. M. & St. P. Ry. Co., Goodnow, Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 15, 1892.

OUTAGAMIE COUNTY

Outagamie county, located in the east central part of the state, has an area of 684 square miles, and a population of 49,102. About 81.3 per cent of the county is in farms, of which 66.6 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is quite gently sloping and without prominent relief. The Fox river flows northward across the southeastern part and the Wolf river flows southward across the northwestern part. The divide between these rivers, forming the highest land in the county, extends northeast-southwest diagonally across the central part of the

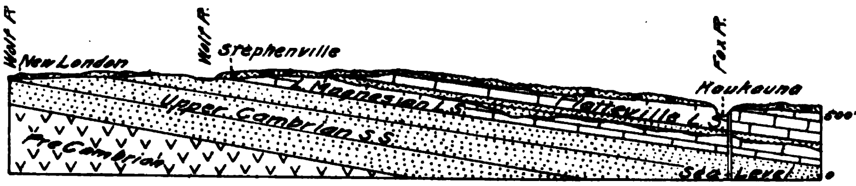

Fig. 55.—Geologic section, east-west, across southern Oconto County.

county. Probably the highest part of the county is in the southwest part, in the vicinity of Medina, which locality has an elevation of 850 to 900 feet above sea level. The lowland along the Fox and the Wolf rivers is a little above 750 feet, hence the maximum range in elevation is between 100 and 150 feet. A belt of undulating drift hills extends northward along the divide, through the vicinity of Greenville and Black Creek.

GEOLOGICAL FORMATIONS

The geological formations are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, the St. Peter sandstone, and the Galena-Platteville (Trenton) limestone. These indurated rock formations are quite generally covered with glacial drift on the divides, and with alluvial sand and gravel, and glacial drift in the valleys. The red lacustrine clay deposit is generally present in the valleys, associated with the stratified sand and gravel, and its stony counterpart worked into the glacial drift is very generally distributed over the upland divides in the southern part of the county. The geological structure is illustrated in figure 55.

The Lower Magnesian formation is variable in character, consisting largely of limestone in some places, as at Kaukauna and Combined Locks, and largely of sandstone and shale in other places, as at Appleton Jct., and Appleton. The most complete well record available appears to be that of the Paper Company well at Combined Locks, which reached the Pre-Cambrian granite after passing through the Trenton, St. Peter, Lower Magnesian and Upper Cambrian formations. In this well (see page 490) there are 28 feet of St. Peter sandstone, 130 feet of Lower Magnesian limestone, and 420 feet of Upper Cambrian (Potsdam) sandstone, the thickness of the St. Peter and Lower Magnesian being essentially the same as in the city well at Kaukauna. These thicknesses for the St. Peter, Lower Magnesian and Upper Cambrian therefore may be taken as fairly representative of these formations in this part of the state.

In the Appleton Jct. well no limestone of the Lower Magnesian was struck, (see page 490) and similar conditions appear to prevail in Appleton.

All of the geological formations have been greatly eroded; hence, there is a great diversity in the thickness of the strata. The usual range in thickness of the geological formations in Outagamie county may be summarized as follows:

Probable range in thickness of formations in Outagamie County.

Formations.	Thickness.
	Feet.
Surface formation	0 to 300
Galena-Platteville (Trenton) limestone	0 to 250
St. Peter and Lower Magnesian	0 to 250
Upper Cambrian (Potsdam) sandstone	100 to 500
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal source of water supply in Outagamie county are the surface deposits of glacial drift and associated alluvial formations, and the sandstone formations underlying the limestone in the southeastern part of the county and immediately underlying the surface drift in the northwestern part.

The general water level is usually less than 100 feet below the surface on the upland slopes and less than 30 or 40 feet from the surface in the valleys. The groundwater in the alluvial deposits in the valleys

and low areas is often under sufficient artesian pressure to develop flowing wells.

FLOWING WELLS

Flowing wells occur in Outagamie county in both the surface deposits and the underlying rock strata. Along the Wolf river and tributaries, surface flowing wells occur at New London, Hortonville, Shiocton, Dale and Medina Jct. and many other places. These wells are generally from 30 to 150 feet deep, the source of the supply being the sand and gravel seams underlying and interstratified with relatively impervious clay beds. These have flows with heads ranging from one to thirty-five feet above the surface.

Along the Fox river, in the vicinity of Appleton, are also many shallow flowing wells that obtain water from gravel seams in the surface formation. The well at Mr. Heid's farm 55 feet deep, which gets its supply from gravel below red clay, is an example. The clay in this locality is often 40 to 80 feet deep, beneath which leaves, twigs and logs are often found. The water in Mr. Heid's well rises several feet above the surface and flows a strong stream.

There are also many deep artesian wells in Appleton and other cities and villages along the Fox river, that draw their supply from the St. Peter, Lower Magnesian and Potsdam formations, as described on the following pages. Several of these wells in Appleton reach depths of 600 to over 800 feet, the head in most favorable places being 10 to 20 feet above the surface. At Kaukauna, down the river from Appleton. the artesian wells that reach through the Trenton and Lower Magnesian limestones have strong flows, rising as high as 35 feet above the surface in the most favorable localities. Flowing artesian wells are also common in Combined Lock and Little Chute.

SPRINGS

Springs are a common source of water supply in this county. An especially large spring is located in the northwest quarter of Sec. 28, and some small ones in the northeast corner of Sec. 18, of the town of Hortonia, along the Wolf river. There are numerous springs along the Fox River, the springs issuing at the contact of the limestone with the overlying drift, or directly from the limestone formation. Some of the springs in Appleton contain hydrogen-sulphide (H_2S). A spring in the southwest quarter of Sec. 31, Town of Grand Chute, contains considerable iron.

WATER SUPPLIES FOR CITIES AND VILLAGES

Appleton. The city of Appleton, located on the Fox river, has a population of 16,773. The city water supply was formerly obtained from three artesian wells, but on account of apparent lack of sufficient water the supply was changed to Fox river. There are two intakes, one of which extends to the center of the south channel of the river to a depth of 8 feet. The average daily pumpage for 1914 was 2,560,000 gallons. The water is filtered by a Jewell mechanical filter of the pressure type. The city sewage empties, without purification, into the river below the intake. It is reported that 90 per cent of the houses are connected with the water supply and sewage systems. It is also reported that the city supply is used mainly for commercial and domestic purposes, and not for drinking.

The three city wells are 6-inch wells, as follows: No. 1, 475 feet, drilled in 1881; No. 2, 675 feet, drilled in 1884; and No. 3, 822 feet deep drilled in 1886. No. 1 is cased 400 feet, and No. 3, 600 feet. The second water works well in Appleton is located about 75 feet east of the first, and the third is about 150 feet northeast of the first, and thus unfortunately so placed as to readily interfere with one another. No separate tests were made of the wells, but at first they furnished collectively about 694.4 gallons per minute, and later decreased to about 520.8 gallons. This decrease in supply is no doubt due largely to the increase in the number of wells put down in the locality, and in part to leakage at the well. These city wells, as above stated, are used very little, or not at all, at present.

The Wisconsin Malt and Grain Company raise their water from a depth of 250 feet by means of an air compressor and get a sufficient supply. This well, the one at George Walters Brewery, and the three at the Fox River Paper Mill, are the heaviest users and keep the water down. In all these wells all surface water is shut out by proper casing, and in some cases the St. Peter supply is also cased off. There are about ten flowing wells that enter the St. Peter sandstone and resemble the Appleton Machine Company's well. Wells of this type are located all along the banks of the Fox river and on the islands in the river. The supply from the St. Peter sandstone is obtained at a depth of about 100 feet, the quantity increasing as the depth in sandstone increases. The main flow from the Potsdam sandstone occurs at about 520 feet. Most of the wells in the St. Peter sandstone are packed, but it is noticeable that wells at low elevations interfere with those at higher elevations. The wells at the Paper Mill, just east of the waterworks wells, have taken considerable of the flow of the latter. The city wa-

ter company abandoned the artesian wells and is now pumping water from the Fox river, which is said to be not satisfactory. It has generally been noted that the sinking of deep wells east of Appleton has lessened the head at Appleton. This was particularly noticeable with the Badger well at Kaukauna, and the well at Combined Locks. From the study of the various wells along Fox river it appears that at Appleton a system could readily be developed by which the city might be supplied entirely with artesian water. This might necessitate, however, a lowering of the head to considerable depth, and would then interfere somewhat with the available artesian supply at the various factories.

Appleton Junction. At Appleton Junction, on the farm of G. H. Murphy, a well 350 feet deep struck no limestone of the Lower Magnesian horizon.

Section of G. H. Murphy well at Appleton Junction.

Formation.	Thickness.
	Feet.
Clay, gravel and sand	75
White sandstone	200
Sandy shale	75
Total depth	350

No accurate record was available of any of the Appleton city wells, so it was impossible to say whether Lower Magnesian limestone is present or not, but from the above record, and those farther east, it appears that the St. Peter formation, (including some Lower Magnesian sandstone) usually rests directly upon the Potsdam in this locality.

Combined Locks. The following is the section of the Paper Company's well:

Log of Well of the Combined Locks Paper Company.

Formation.	Thickness.
	Feet.
Drift	21
Galena-Platteville (Trenton) limestone	191
St. Peter sandstone	28
Lower Magnesian limestone	130
Upper Cambrian (Potsdam) sandstone	420
Bottom (in granite)	790

Another well put down 40 feet east of, and about 20 feet higher than the Paper Co. well, struck its first flow at a depth of 240 feet in the St. Peter sandstone and flowed only a few inches above ground. The well probably ended before passing very far into the Potsdam.

Kaukauna. This city, with a population of 4,717, is located on the Fox river, about 7 miles below Appleton. The city water supply is obtained from three artesian wells, the two first drilled being 8-inch wells, 643 feet deep. The third well is 798 feet deep. The wells flow into a reservoir 60 feet in diameter and 15 feet deep. The average pumpage is about 249,000 gallons. About 50 per cent of the houses are connected with the city supply. The city has a sewage system, the sewage being emptied, without purification, into the Fox river. At Kaukauna the first two wells put in by the city in 1896 gave the following log:

Logs of City Wells, Kaukauna.

Formation.	Thickness.
	Feet.
Soil	22
Galena-Platteville (Trenton) limestone	176
St. Peter sandstone	25
Lower Magnesian limestone	118
Upper Cambrian (Potsdam) sandstone	302
Total depth	643

The natural flow of each well yielded 5 gallons per minute at 285 feet, 25 gallons at 370 feet, and reached 200 gallons at 550 feet. The Potsdam was not passed through. Hard pumping draws water down about 2 feet. These deep wells lowered the two old city wells, which are located on the north and south banks of the valley, about 50 feet higher than the city wells, so that the water in the old wells stands about 20 feet below the surface. A well was put down for the Badger Paper Company, which has a strong pressure at present, but is not used extensively, part of the water being piped to the adjacent mill and used for drinking and condensing purposes.

Numerous other wells have been put down to the St. Peter sandstone. The wells when allowed to flow continuously interfere with each other. The best wells are packed at a depth of about 100 feet.

Little Chute. Population, 1,354. The water is obtained from private wells, many of which are flowing. The Little Chute Paper Company's well is 360 feet deep, obtaining its supply from the St. Peter sandstone.

Hortonville. Population, 863. The water supply is obtained from common wells from 40 to 150 feet deep. On low ground there are a number of flowing wells, ranging in depth between 37 and 113 feet. The water in the flowing wells is obtained from sand and gravel, with head from 4 to 20 feet above the ground.

QUALITY OF THE WATER

The mineral analyses of various water supplies of Outagamie county are shown in the following table. Most of the waters analyzed are hard with a moderate mineral content. The waters of highest mineral content are from the southeastern limestone-covered portion of the county. In the northwestern part of the county, adjacent to and west of the Wolf river, where there is no limestone, waters of appreciably lower mineral content are likely to prevail. Of the waters analyzed, the surface water from the Fox river has the lowest content of mineral matter. The appreciable content of organic matter in the Appleton city water supply is characteristic of river water. The water from the shallow flowing wells at Hortonville, all probably in the surface deposits, as well as that from the spring at Appleton, are much lower in mineral content than the deep artesian wells at Appleton, which draw their supply from the sandstones underlying the Trenton limestone. The higher content of mineral in the deeper water is due to the increase in sulphates rather than chlorides. As most of the well waters analyzed in the above table are from flowing wells, and therefore likely to be uncontaminated by seepage of surface waters, the variable content of chlorine is noteworthy. Waters unusually high in mineral content are from shallow wells 8 feet deep in the Trenton, No. 8, and from the deep artesian wells from the sandstone, No. 12.

The Fox river water at Kaukauna, No. 7, contains 1.36 pounds of incrusting solids in 1,000 gallons. The railroad well at Hortonville, No. 4, contains 2.95 pounds in 1,000 gallons, while the deep flowing well at Kaukauna, No. 10, contains 5.49 pounds in 1,000 gallons.

Mineral analyses of water in Outagamie County.

(Analyses in parts per million)

	River.		Spring.	Surface deposits.		
	1.	2.	3.	4.	5.	6.
Depth of well.....................feet..	....	....	....	20	....	....
Silica (SiO_2)..............................	6.1	11.2	15.	16.4	15.9	16.9
Aluminium and iron oxides (Al_2O_3+ Fe_2O_3)................................	0.8	6.	2.	0.3	2.0	3.4
Calcium (Ca)................................	32.3	30.4	24.	69.6	70.2	71.5
Magnesium (Mg)........................	19.1	13.7	16.	43.4	35.9	46.8
Sodium (Na)............................. Potassium (K)	10.1	4.4	32.	5.0	1.0	4.4
Carbonate radicle (CO_3)	80.3	79.4	128.	190.8	188.2	187.2
Sulphate radicle (SO_4)...................	36.4	....	16.	34.6	9.3	54.9
Chlorine (Cl)................................	6.7	6.8	4.	6.9	1.5	6.8
Organic matter............................	....	20.	11.	....	....	....
Total dissolved solids..............	192.	152.	237.	367.	324.	391.

	Surface Deposits.	Galena or Cincinnati limestone.	St. Peter and Upper Cambrian sandstone.			
	7.	8.	9.	10.	11.	12.
Depth of well....................Feet..	....	8	285	555	600	798?
Silica (Sio)..................................	15.0	.86	....	8.4	4.4	27.95
Aluminium and iron oxides (Al_2O_3+ Fe_2O_3)	Trace	3.17	....	1.0	....	1.88
Calcium (Ca)................................	77.3	410.95	119.2	198.5	158.2	272.36
Magnesium (Mg)........................	38.5	115.56	15.2	20.4	31.3	20.57
Sodium (Na)................................	5.5	63.78	24.8	26.3	2.2	146.36
Potassium (K)..............................		68.66			3.9	
Carbonate radicle (CO_3)...............	135.1	311.08	120.0	210.1	146.6	265.80
Sulphate radicle (SO_4).................	79.6	1,133.89	194.7	273.7	296.0	603.59
Chlorine (Cl)...............................	8.5	25.0	8.4	12.8	7.1	12.22
Total dissolved solids..............	380.	2133.	482.	751.	647.	1351.

1. Fox River at Kaukauna, Analyst, G. M. Davidson, June 26, 1909.
2. Fox River, City Water Supply at Appleton, Analyst, Dearborn Drug & Chem. Co., Oct. 2, 1901.
3. Mineral Spring, Appleton, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 32, 1877.
4. Well of C. & N. W. Ry. Co., Hortonville, Analyst, G. M. Davidson, Aug. 1, 1894.
5. Artesian well at Hortonville, Analyst, G. M. Davidson, March 2, 1900.
6. Well at Mortonville, 500 feet S. E. of C. & N. W. Station, Analyst, G. M. Davidson, Aug. 1, 1894.
7. Well at Appleton, Analyst, Mil. Ind. Chem. Institute.
8. Well on farm of Thomas Fox in town of Buchanan, Analyst, Victor Lehner, Jan. 8, 1909.
9. Well of A. A. Kern, Kaukauna.
10. Flowing artesian well, Kaukauna, Analyst, G. M. Davidson.
11. Well of George Walters, Appleton, Analyst, American Brewing Academy.
12. Well of City Water works, Kaukauna, Analyst, G. M. Davidson, April 26, 1911.

OZAUKEE COUNTY

Ozaukee county, located in the southeastern part of the state, on Lake Michigan, has an area of 276 square miles, and a population of 17,123. About 94 per cent of the county is in farms, of which 78 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is an undulating plain sloping eastward towards Lake Michigan. The upland ridges and the stream valleys trend north and south, approximately parallel to the shore of the lake. The principal drainage line is the Milwaukee river, which enters the county from the west in the northwestern part and flows south through the central part. The Cedar Creek is the principal tributary.

The elevation of Lake Michigan is 581 feet above sea level. The altitude of the uplands adjacent to the lake is between 700 and 800 feet, while altitudes of the upland ridges 6 or 8 miles farther west, along the western border of the county, usually reach up to over 900 feet, the highest points located in the north western part, in Saukville and Fredonia, being 1,000 feet.

The altitude of the valley bottom of the Milwaukee river, which is relatively broad and shallow, is about 660 feet at the southern boundary of the county and about 800 feet in the northwestern part west of Fredonia, the valley of the Milwaukee river at Saukville only about 3 miles west of the lake shore at Port Washington being nearly 200 feet above the level of Lake Michigan.

The most prominent reliefs are the steep banks of the shore of Lake Michigan which are from 120 to 140 feet high as far north as Port Washington, north of which point they gradually descend to a gently sloping shore. In the northwestern part of the county the difference in elevation is generally 100 to 200 feet.

GEOLOGICAL FORMATIONS

The rock formation throughout the county is mainly the Niagara limestone. In the northeastern part of the county, south of Lake Church, are deposits of Devonian limestone. The surface formations of glacial drift and lacustrine deposits overlie the limestone. The geological structure is illustrated in the cross section, Fig. 56, extending east and west through Ozaukee and Washington counties.

The surface deposits as usual vary greatly in thickness in various parts of the county, but are usually from 50 to 100 feet thick. In many places, however, the drift is very thin and in places the limestone outcrops at the surface. The known maximum thickness of the surface deposits is 150 feet, but in some of the drift ridges, or in the pre-glacial valleys, a thickness of 200 or 250 feet may be expected.

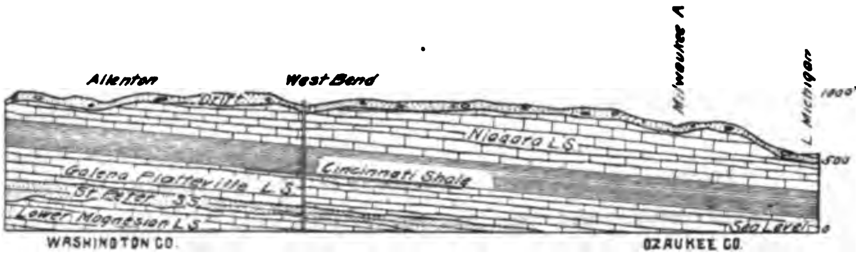

Fig. 56.—Geologic section, east–west, across northern Washington and Ozaukee Counties.

The thickness of the Niagara limestone is also variable on account of the extensive erosion of this formation before the surface deposits, and also probably before the overlying shales, were laid down upon it. Only one complete record of a well that has penetrated through the Niagara has come to hand in this county, namely, that of the C. & N. W. Ry. Co. at Mequon. The log of this well as interpreted by F. T. Thwaites, from a fairly complete set of samples, is as follows:

Log of Well of C. & N. W. Ry. Co. at Mequon.

Formation.	Thickness.
	Feet.
Surface	194
Devonian gray shale (Hamilton)	141
Niagara hard gray limestone	300
Cincinnati shale	216
Galena-Platteville (Trenton) limestone	219
St. Peter Lower Magnesian and Upper Cambrian (Potsdam) sandstone	350
	1,420

It is of special interest to note the presence of 141 feet of gray shale beds of Devonian, overlying the hard gray limestone of the Niagara, which has a thickness of only 300 feet. The formations below the Trenton are wholly sandstone, the Lower Magnesian horizon, as at Milwaukee, being wholly represented by sandstone strata. Judging from the thickness of the Niagara formation in this well and the adjoining counties to the south, west and north, a minimum thickness of 200 feet may

be expected, while the maximum thickness may reach 450 to 550 feet.

The small deposits of Devonian (Hamilton shale) which overlie the Niagara at Druckers quarry and the Lake Shore Stone Co. quarry, south of Lake Church, show a thickness of only 12 or 13 feet. These deposits of the Devonian limestone, and that recorded in the Mequon well, are the only ones known to occur in the county.

The formations underlying the Niagara probably attain the usual thickness of these formations in adjacent parts of eastern Wisconisn. The usual thickness of the formations from the surface down to the Pre-Cambrian granite may be summarized as follows:

Thickness of Geological Formations in Ozaukee County.

Formation.	Thickness.
	Feet.
Surface deposits	0 to 300
Hamilton shale (Milwaukee formation)	0 to 200
Niagara limestone	200 to 550
Cincinnati shale	200 to 250
Galena-Platteville (Trenton) limestone	200 to 250
St. Peter and Lower Magnesium	200 to 250
Upper Cambrian (Potsdam) sandstone	600 to 700
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing formations are the surface deposits of glacial drift and the Niagara limestone. The formations underlying the Niagara, so far as known, have not been drawn upon for water supplies.

The permanent water level in both the drift and limestone is near or at the surface in the valleys and very generally less than 100 feet below the surface on the slopes of the upland ridges. For many years shallow open surface wells in the drift only 10 to 30 feet deep on the uplands supplied sufficient water for domestic purposes. In recent years, however, most of these wells have been deepend by drilling down to the rock, and now obtain the supply from the permanent water level in gravel beds which usually overlie the limestone rock.

Wells in the limestone range in depth from 10 to 150 feet, obtaining an abundant supply from the open fractures and fissures which permeate the rock. Wells in the limestone are likely to be more constant in the supply and of better quality than those obtained from the drift.

FLOWING WELLS

Flowing wells are obtained in Ozaukee county in the surface deposits of gravel and sand underlying clay and also in the underlying limestone rock.

In the valley of the small stream which empties into the lake at Port Washington, are 12 or more artesian wells that derive their flow from the water bearing gravel at the junction of the drift with the indurated rocks below. These wells range in depth from 120 to 150 feet according to their elevation above the lake and the thickness of the drift, and the water flows from 5 to 25 feet above the surface.

General Section of Flowing Wells at Port Washington.

Formation.	Thickness.
	Feet.
Gravel	0—10
Hardpan	40—60
Blue clay	40—50
Beach sand	30—60
Porous rock	0— 5

The beach sand and porous rock are the water-bearing strata. In most cases a good flow is obtained in the sands at the surface of the rock, but in few instances where these sands are troublesome in clogging the pipes the wells are sunk a few feet into the rock where the same water is found in crevices, clear and free from sediment.

The water on the upland ridges west of the lake is obtained from the limestone, but fails to rise to the surface. There are many rather shallow dug wells in the county, the deeper drift wells being, for the most part, confined to the valleys where flows may be obtained. Shallow flowing wells are found at various places between West Bend and Port Washington.

Shallow flowing wells are also obtained along the river bottoms and lowlands as far inland as Newberg in Washington county. The wells are of the same general character as those at Port Washington and West Bend.

Deep artesian flowing wells obtaining their supply from the strata underlying the Niagara limestone and Cincinnati shale have not been drilled in Ozaukee county, but flowing wells of this type may reasonably be expected up to the altitudes of 100 feet above Lake Michigan

and may be possible up to over 150 feet. The county, however, is generally above this altitude, as already discribed, except along the lake shore.

SPRINGS

Springs issue in various parts of the county from the drift and the limestone. The Hilgen Spring at Cedarburg issuing from the drift is a well known spring. A number of springs also occur in the vicinity of Port Washington. Many of the small streams that flow into the Milwaukee river are fed by springs, as illustrated in the vicinity a mile east and 2½ miles southeast of Fredonia.

WATER SUPPLIES FOR CITIES AND VILLAGES

Port Washington. This city located on Lake Michigan has a population of 3,792. The city recently installed a water supply system and sewage disposal plant. The water supply is obtained from the lake, the intake pipe extending 1,500 to 2,000 feet into the lake at a depth of about 38 feet. The sewers empty into the harbor, and if the water becomes polluted from this source, filter beds or septic tanks will be used to treat the sewage before it is emptied into the lake.

Flowing wells from the Niagara limestone similar to those at Manitowoc are obtained at Port Washington. Numerous flowing wells are also obtained from the drift, as at other points along the lake shore. The Niagara limestone is the chief formation upon which to depend for water both north and west of the city.

The well owned by the Biederman Brewing Company is the strongest in the city, and when allowed to flow freely will drain most of the wells at a higher level.

Cedarburg. Cedarburg, population 1,777, is located on Cedar river. The water supply is obtained from private wells reported to be from 10 to 40 feet in the rock, the average depth being 20 feet.

Fredonia. Water in Fredonia is supplied from private wells 15 to 125 feet in rock.

QUALITY OF THE WATER

The mineral analyses of various waters of Ozaukee county are shown in the folowing table. The waters from the surface deposits and Niagara limestone are hard or very hard waters of moderate mineral content and are "calcium carbonate" waters, while that from the 1,420

foot well at Mequon, from the St. Peter and Potsdam sandstone, is highly mineralized and is distinctly a "calcium sulphate" water. The latter water is suitable for both drinking and boiler use.

The water of Analysis No. 8, contains 19.62 pounds of incrusting solids in 1,000 gallons as compared with 2.88 pounds in 1,000 gallons from the well at Port Washington, No. 7, and with 0.99 pounds in 1,000 gallons of Lake Michigan water, No. 1.

Mineral analyses of water in Ozaukee County.

(Analyses in parts per million)

	Lake.	Spring.	Surface deposits.			Niagara limestone.		St. Peter and Upper Cambrian sandstone.
	1.	2.	3.	4.	5.	6.	7.	8.
Depth of well............feet..	....	....	....	14	133	170	245	1420
Silica (SiO_2)....................	5.6		13.8				8.9	19.0
Aluminium and iron oxides		6 0		8.7	19.3	6.5		
($Al_2O_3+Fe_2O_3$)..............	2.4		0.8				0.5	6 8
Calcium (Ca)....................	30.8	68.4	83.1	77.6	66.0	77.5	68.8	452.1
Magnesium (Mg)...............	9.2	24.4	37.0	35.9	33.8	38.5	40.9	55.7
Sodium and potassium (Na+K)	5.7	7.8	5.3	14.6	16.9	16.0	12.3	69.3
Carbonate radicle (CO_3).......	66.7	167.4	168.9	183.4	194.5	199.7	167.8	152.7
Sulphate radicle (SO_4).........	9.4	7.6	78.1	35.9	14.8	35.0	74.9	1769.1
Chlorine (Cl)....................	4.7	1.2	5.8	20.9	1.3	12.9	6.6	27.7
Organic matter.................	....	....	34.6	....	....	....	13.0	....
Total dissolved solids......	135.	282.	427.	377.	347.	386.	381.	2552.

1. Lake Michigan, City Water Supply, Port Washington, Analyst, G. M. Davidson, Nov. 27, 1907.
2. Spring, Thiensville, Analyst, Chemist C. M. & St. P. Ry. Co., July 6, 1891.
3. Flowing well, Port Washington, Analyst, G. M. Davidson, Nov. 22, 1907.
4. Well of C. M. & St. P. Ry. Co., Saukville, Analyst Chemist, C. M. & St. P. Ry. Co., July 7, 1891.
5. Flowing well, Wilson Hotel, Port Washington, Analyst, Chemist, C. M. & St. P. Ry. Co.
6. Well of C. M. & St. P. Ry. Co., Saukville, Analyst, Chemist C. M. & St. P. Oct. 19, 1894.
7. Well of C. & N. W. Ry. Co., Port Washington, Analyst, G. M. Davidson, April 27, 1907.
8. Well of C. & N. W. Ry. Co., Mequon, Analyst, G. M. Davidson, May 7, 1907.

Pepin County

Pepin county, located in the west central part of the state, has an area of 239 square miles and a population of 7,577. About 89.8 per cent of the county is laid out in farms, of which 51.7 per cent is under cultivation.

SURFACE FEATURES

The surface of Pepin county consists in about equal proportion of low valley bottom land and dissected upland plain. The valley bottoms lie along the Mississippi and Chippewa rivers and their tributaries. The principal tributaries of the Chippewa are the Eau Galle river and Plum Creek on the west and Beaver Creek on the east. The altitude of the valley bottoms is a little less than 700 feet and of the uplands a little over 1,200 feet. The valley sides are quite abrupt, especially adjacent to the larger rivers.

The soils in the valley bottoms are mainly sands and sandy loams, and those upon the uplands are heavier silt loams.

GEOLOGICAL FORMATIONS

The geological formations as shown in Fig. 22 are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, and the alluvial gravel and sand along the Chippewa and Mississippi rivers. Some glacial drift is present on the uplands in the western part of the county. The contact of the Upper Cambrian sandstone with the overlying limestone a short distance southeast of Durand is at an elevation of 1,090 to 1,100 feet above sea level. The contact of the sandstone with the underlying pre-Cambrian granite in the Court House well is 400 feet below the surface, at an elevation of 320 feet above sea level (See diagram figure 22) which makes a total thickness of 770 feet for the Upper Cambrian (Potsdam) sandstone formation at Durand.

The surface formation, consisting mainly of the alluvial deposits in the valleys, probably reaches a maximum thickness of 200 to 250 feet in the middle of the Chippewa river channel. The thickness of the rock formations is variable on account of the extensive erosion of the strata. It is only on the summits of the uplands that the Lower Magnesian limestone is present, and the complete thickness of the Upper Cambrian (Potsdam) sandstone is preserved only in those ridges capped by the

limestone. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Pepin County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Lower Magnesian limestone	0 to 200
Upper Cambrian (Potsdam) sandstone	200 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The important sources of the water supply are the alluvial sands and gravels and the sandstone. There are some shallow wells upon the uplands, as at Lund, which vary in depth from 20 to 35 feet, obtaining the water supply from the clay and loess overlying the limestone. Wells that penetrate the rock on the highest elevations, however, generally have to go down to the general water level, to a depth of 200 to 350 feet. Along the river bottoms the wells are generally less than 50 feet deep and obtain their water supply from the alluvial sands and gravels.

FLOWING WELLS

Flowing wells occur in the valley bottoms, in the surface formation and the underlying sandstone. The strongest flows are obtained from the sandstone, the normal head at Durand being 30 to 40 feet above the level of the river, an altitude of about 735 to 740 feet above sea level.

The log of the artesian well at the County Court House in Durand, furnished by Mr. Bowman, which gives an accurate statement of the formations, is as follows:

Log of Pepin County Court House Well, Durand.

Formation.	Thickness.
	Feet.
Soil and surface	12
Upper Combrian (Potsdam):	
Shale (relatively impervious)	190
Shale and sandstone (transition beds)	10
Sandstone, brownish	88
Sandstone, coarse	160
Pre-Cambrian:	
Granite, decomposed, soft	30
Granite, hard	7
Total	437

The elevation of the curb of the Court House well is 720 feet above sea level and the water will rise 17 feet above the curb. At the Durand Brewing Company well, the formations are the same, passing through 30 feet of soft decomposed granite before striking the hard granite at bottom. At the Stokes Hotel, the artesian well is drilled 444 feet deep, stopping in hard granite.

The first flow is struck after passing through the relatively impervious shale and striking the sandstone at a depth of about 200 feet. The first flowing wells were drilled in 1900 and all the earlier ones were drilled down to granite. Many of the later ones, however, were drilled only 200 feet and obtained as strong a flow as the deeper ones. There are now probably 25 or 30 flowing wells in the city. Some of these have a less depth than 200 feet, stopping in the shale, and probably obtain their flow from leakage into the shale from the deeper wells.

The wells vary from 2 to 6 inches in diameter. The temperature of the water is 51° F.

The Durand wells are all fed from the same horizon and interfere greatly with one another. The best pressure on the lowest ground is 14½ pounds, while on the high ground it is much less. By opening to continuous flow any one of the 6-inch wells on low ground the flows of the wells on higher ground would be decreased or destroyed.

All the wells show about the same series of strata. There are slight differences in head, however, unless proper precautions are taken to prevent leakage at a number of the wells. Instead of casing the wells into the impervious shale and making a firm contact the water of some of the wells is allowed to escape in the soft porous sandstone above the shale. That some of the wells are not properly cased at present may be seen by the leakage around pipes where a good sized stream comes up on the outside of the casing. In others, as at Robert Kroeft's well the leakage into the sand rock over the shale was so great as to cause an old well sunk into this stratum to flow shortly after the flow was struck in the artesian well. Nearly all of the shallow wells have much more water now than before artesian wells were sunk, and some of the basements are kept moist from the leakage at the artesian wells.

Unless these defects are remedied, all the wells will suffer from the carlessness of a few of the owners of flowing wells. The shale is hardest near the center of the bed and into this the casing ought to be sunk. The accompanying diagram Fig. (57) shows the leakage at some of the wells, due to improper casing, and shows at the same time how this condition affects wells in the vicinity. On the same figure is shown a well which is properly cased so as to avoid all leakage and in which the pipe may be easily repaired.

Well "b" on the lot of Robert Kroeft was drilled first, and by pumping yielded only surface water from sandy soil and soft underlying sand and rock. After drilling well "c" in which artesian water was obtained, well "b" also began flowing, showing that the water escapes into the soft sand rock through the lack of proper casing. The casing should extend several feet into the impervious shale.

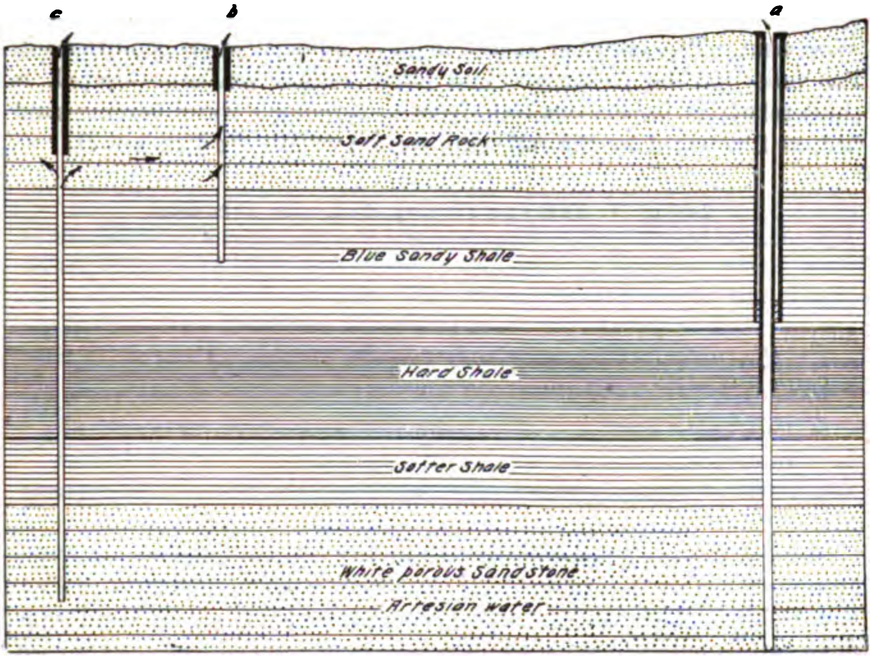

Fig. 57.—Diagram showing proper and improper casing of artesian wells at Durand. (After A. R. Schultz)

a = properly cased well.
b = shallow well.
c = improperly cased well.

In well "a" the outer casing has been extended into the shale, then the bore of the well was decreased and the inner casing extended down to the hardest portion of the impervious shale. The contact between the two casings is further sealed by a few feet of cement, thus making a joint secure against any of the water working up along the outside of the casing. A well cased in this manner will last for years and is easily repaired in case the inner tubing corrodes so as to allow too much leakage. The two casings are not necessary to insure a properly cased well if the pipe is extended well into the shale and cemented near the base to avoid leakage.

At the home of W. Hasting's, Sec. 7, T. 25, R. 14, seven miles west

of Durand, near Arkansaw, in the valley of the Arkansaw Creek, a well was drilled to a depth of 257 feet, 145 feet in alluvial gravel and 112 feet in the Potsdam formation, a flow being obtained at 120 to 145 feet. Other artesian flows have been obtained in this locality in the valley deposit, having a maximum flow of 6 feet above the Creek level and 6 in. above the well curb.

The underground water conditions similar to those along the Arkansaw Creek which have developed artesian flows are not uncommon in Wisconsin. The essential factor in developing artesian conditions in the valley of the Arkansaw, and other valleys similarly located, is thick relatively impervious clay deposit overlying a water-bearing sand bed, as illustrated by the following section of Mr. Hasting's well:

Log of W. Hasting's Flowing Well, near Arkansaw.

Strata.	Thickness.
Alluvial.	Feet.
Clay soil	35
Sandy clay	85
Coarse sand (source of flow)	25
Upper Cambrian sandrock, soft	12
Blue sandy shale	23
Sandrock, grayish white	77
Total depth	257

Another flowing well, reported depth 100 feet, was drilled on lower ground on the north branch of the Arkansaw creek on the farm of Herman Ogallie, which proves conclusively that under favorable conditions flows can be obtained up the minor valleys of the Chippewa, as indeed up all the minor valleys of the Mississippi river, and at considerably higher elevation than along the main streams.

The valley fill in this locality, at the mouth of the Arkansaw creek and in the Eau Galle river valley, has a known maximum depth of 185 feet. The strata of alluvial deposit in the valley have a well defined inclination down the valley, and hence a typical artesian slope is developed, the water in the underlying pervious sand strata being held under pressure by the relatively impervious overlying clay strata. It is possible that water under pressure from the Potsdam sandstone seeps into the valley deposit and thus moderately assists in developing artesian conditions. However, the structure of the valley deposits themselves is amply competent to furnish artesian flows of the character developed in these valleys. (Compare with shallow artesian wells in the Fox and Rock river valleys, pages 90–7).

WATER SUPPLIES FOR CITIES AND VILLAGES

Durand. Durand, the county seat, on the Chippewa river, has a population of 1,503. A public water supply was recently installed. The supply is obtained from a 10-inch well, 301 feet deep. Sandrock was struck at depth of 6 feet. The well flows with pressure of 12 lbs. at the curb. Shallow wells in this city obtain water at depths of 20 to 40 feet, depending upon the elevation above the river. There are also a number of flowing artesian wells in this city, as already described.

QUALITY OF THE WATER

Only two analyses of water of Pepin county are available, namely, those of a spring and a well at Durand. The source of the spring water is the Upper Cambrian sandstone. The water is hard carbonate water of moderate mineral content. The water from wells in the alluvial sands along the Chippewa river and main tributaries is likely to contain a smaller amount of mineral than this spring water, while that from the sandstone, where overlain by limestone, is likely to contain a slightly larger amount of mineral.

Mineral analyses of water in Pepin County.

(Analyses in parts per million)

	Spring.	Upper Cambrian Sandstone.
	1.	2.
Depth of well.....feet	.....	172
Silica (SiO_2)..... Aluminum and iron oxides ($Al_2O_3+Fe_2O_3$).....	2.5	7.0
Calcium (Ca).....	43.5	64.5
Magnesium (Mg).....	25.1	34.4
Sodium and potassium (Na+K).....	8.4	7.8
Carbonate radicle (CO_3).....	133.4	180.0
Sulphate radicle (SO_4).....	6.0	15.9
Chlorine (Cl).....	1.5	0.6
Total dissolved solids.....	220.	310.

1. Durand Spring, at Durand, Analyst, Chemist, C. M. & St. P. Ry. Co., Dec. 5, 1891.
2. Railroad well at Durand, Analyst, Chemist, C. M. & St. P. Ry. Co., Apr. 6, 1891.

Pierce County

Pierce county, located in the northwestern part of the state, has an area of 543 square miles, and a population of 22,079. About 96.4 per cent of the land of this county is in farms, of which 58.7 per cent is under cultivation.

SURFACE FEATURES

The surface of Pierce county is an upland plain moderately dissected in the northern part, but deeply trenched by the southward flowing streams in the central and southern part. The main upland in the central and eastern part has a prevailing altitude of about 1,200 feet,

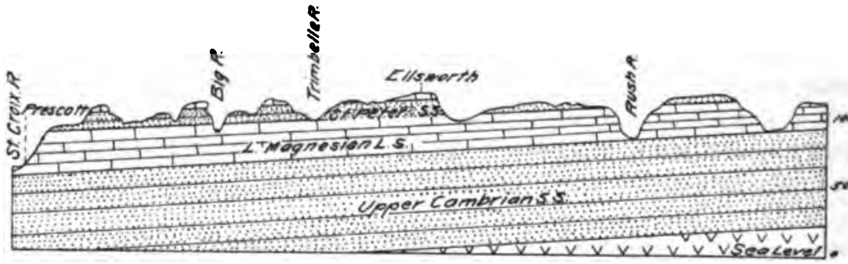

Fig. 58.—Geologic section, east-west, across Pierce County.

descending somewhat to the west towards the St. Croix and Mississippi rivers, where only the mounds retain this altitude. The lowest valley bottoms usually range between 680 feet along the Mississippi to 900 feet up the tributary valleys. The valley sides of the St. Croix and Mississippi rise abruptly from 300 to 400 feet above the river bottoms.

The soils are generally silt loams on the uplands and sandy loams in the valley bottoms.

GEOLOGICAL FORMATIONS

The geological formations beginning at the bottom are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone which includes the Shakopee and Oneota formations, the St. Peter sandstone and the Galena-Platteville (Trenton) limestone. The two latter formations occur only in the highest elevations. Glacial drift and loess are quite abundant over most parts of the county. Alluvial sand and gravel is present in the valley bottoms. The geological sturcture is illustrated in figure 58.

The thickness of the surface formations of glacial drift, mainly confined to the uplands, and of the alluvial filling, mainly confined to the valleys, is quite variable but probably reaches a maximum of 200 to 250 feet in a few places, though in general it is much less than 100 feet. The thickness of the rock formations is variable on account of the extensive erosion of the strata. The complete thickness of a formation is preserved only where protected by the next overlying formation. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Pierce County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena-Platteville (Trenton) limestone	0 to 150
St. Peter and Lower Magnesian	0 to 300
Upper Cambrian (Potsdam) sandstone	400 to 800
The Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing horizon is principally the Upper Cambrian sandstone formation, though all the other formations furnish a supply wherever favorably situated. Springs are numerous along the valley bottoms. An especially favorable source for springs is along the contact of the Lower Magnesian limestone and underlying Upper Cambrian sandstone, and also within the sandstone formation. Wells vary in depth from 10 to 20 feet, along the valley bottoms, to 300 and 400 feet, upon the highest uplands. On the uplands open dug wells often find sufficient water in the overlying drift or St. Peter sandstone where these attain a sufficient thickness.

FLOWING WELLS

A flowing well occurs at River Falls, the source of the flow being in the Upper Cambrian sandstone. The flow at River Falls is of relatively low pressure, the head being only 10 feet above the curb in the city well, No. 3, an altitude of about 878 feet. Only one other record of a flowing well is at hand, namely that at Maiden Rock. Other flowing wells could undoubtedly be developed on low ground adjacent to the Mississippi river, as well as up the tributary valleys.

A deep artesian flowing well was recently drilled for the Maiden Rock Lumber Co. at Maiden Rock by Bowman & MacMahon of Durand, having the following log:

Log of Maiden Rock Lbr. Co.'s Artesian Well, Maiden Rock.

Formation.	Thickness.
	Feet.
Surface sand	80
Upper Cambrian sandstone	552
Total depth	632

The elevation of the curb is about 10 feet above Lake Pepin. Two flows were struck, one at 200 feet, raising the water 4 feet above the curb, and the other at 632 feet, raising the water 34 feet above the curb. The first flow was shut off by a 6-inch casing, and below this extends a 4-inch casing to the second flow. The head of the second flow is therefore about 44 feet above the level of Lake Pepin.

On the Minnesota side of the Mississippi flows have been obtained at Hastings[1] with normal head of 14 feet above the surface, and at Red Wing[2] the original head being as high as 75 feet above the surface. The strongest head in Red Wing at present, that of the C. & G. W. R. R., is reported to be 28 feet above the surface.

Flowing wells in the surface formations of the alluvial filled valleys may be reasonably expected in various parts of the county where the alluvial deposit contains relatively impervious strata of silt or clay, either overlying or interstratified with water-bearing sand and gravel.

SPRINGS

A few springs occur at the horizon of shale at the base of the Platteville limestone and at the base of the St. Peter sandstone. The largest and most important springs, however, occur near the base of the Lower Magnesian limestone. Springs of this type are the source of many of the permanent streams of the county, and are distributed along many of the stream bottoms. These springs are a common source of water supply for many of the farmhouses and often determine the location of the farm buildings in the valley bottoms.

WATER SUPPLIES FOR CITIES AND VILLAGES

Ellsworth. Ellsworth, the county seat of Pierce county, has a population of 1,005. It is located upon the upland, capped with Galena-Platteville (Trenton) limestone. The St. Peter sandstone is exposed along the side of the valley in the eastern part of the city, and the

[1] Minn. Geol. Survey, 13th Ann. Rept. 1884, p. 56–57.
[2] U. S. Survey Water Supply Paper 256, p. 194.

Lower Magnesian limestone along the bed of the adjacent Isabel Creek. The elevation of the railroad station is 968 feet, the top of the upland is about 1,200 feet. The city supply is derived from the Upper Cambrian (Potsdam) sandstone, from a 6-inch well, 609 feet deep, located on the ridge. A limited sewage system is installed, the sewage being emptied into a ravine. About 50 per cent of the houses connect with the city water supply. Private wells are from 14 to 150 feet deep.

River Falls. River Falls, situated on Kinnickinick river, has a population of 1,991. The city water supply is derived from three 8-inch wells, as follows:

River Falls City Wells.

Well.	When drilled.	Diameter, inches.	Depth, feet.	Elevation of curb.
No. 1	1893	8	504	893
No. 2	1898	8	396	893
No. 3	1902	8	620	868

In wells 1 and 2 the water originally flowed at the surface, but at present only rises to 6 feet of the surface, and in No. 3, the normal head is 10 feet above the surface. Well No. 1 is cased 100 feet, and No. 2, 240 feet. The logs of wells No. 1 and No. 3 are as follows:

Logs of River Falls City Wells.

Formation.	Well No. 1. thickness.	Well No. 3. thickness.
	Feet.	Feet.
Pleistocene.		
Sand and gravel	5	9
Lower Magnesian.		
Hard Lime Rock interspersed with layers of sandstone	256	240
Upper Cambrian (Potsdam).		
Sandstone	60	50
Blue shale	12	20
Sand rock (first flow)	55	75
Sand rock and shale	26	12
Green shale	90	202
Sand rock		12
Total depth	504	620

Wells No. 1 and No. 2 are within 80 feet of each other, and No. 3, about three-fourths of a mile distant, below the dam. Water under sufficient pressure to flow was struck in No. 1 and No. 2 at a depth of 390 to 400 feet, with no perceptible increase in pressure after that. After No. 3 was drilled, the water sank in earlier drilled wells to 6 feet below the surface. The flow in the new well is at least 200 gallons per

minute, and will stand pumping at that rate for 20 hours, though it is not known how much the water level drops.

Private wells in the city obtain water from depth of 20 to 30 feet, depending upon elevation above the river. About 60 per cent of the houses have water connections. The sewerage, without treatment, empties into the Kinnickinick river.

Spring Valley.—Spring Valley situated upon the Eau Galle river, has a population of 972. The city is located on alluvial gravel and sand in the valley bottom. The city supply is obtained from an 8-inch well 169 feet deep in the gravel and sand. Estimated daily capacity of the city well is 130,000 gallons, the average daily pumpage is about 18,000 gallons. No sewerage system is installed. About 30 per cent of the houses connect with the city supply. Private wells are from 30 to 160 feet deep.

Prescott. This city, situated on the Mississippi river at the mouth of the St. Croix, has a population of 936. A city water supply system was recently installed, the supply being obtained from 4 drive wells 16 feet deep, located near the river. The private wells are from 10 to 100 feet deep in gravl and limstone.

Elmwood. Elmwood, population 585, has a public water supply, obtained from a well 180 feet deep, mainly in sandstone.

QUALITY OF THE WATER

Only one complete analysis of the waters of Pierce county is at hand, namely that of water from city well No. 1 of River Falls. Judging from the geological formations, all the waters from the surface formations, as well as that from the underlying rock, are likely to be hard waters of moderate mineral content in this county.

Mineral analyses of water in Pierce County.
(Analyses in parts per million)

	1.
Depth of well........feet..	504
Silica (SiO_2)........	34.2
Iron oxide (Fe_2O_3)........	18.1
Calcium (Ca)........	80.1
Magnesium (Mg)........	10.9
Sodium and potassium (Na+K)........	....
Carbonate radicle (CO_3)........	[illegible]
Sulphate radicle (SO_4)........	124.4
Chlorine (Cl)........	....
Total dissolved solids........	337.

1. City Water Supply, River Falls, Analyst, W. Lehnen.

Polk County

Polk county, located in the northwestern part of the state, has an area of 933 square miles and a population of 21,367. About 63.2 per fleent of Polk county is laid out in farms, of which 39.6 per cent is under cultivation.

SURFACE FEATURES

The topography is undulating, quite deeply trenched along the St. Croix river, but usually a nearly level plain in the interior of the county. The drift is characterized by choppy morainic features in the

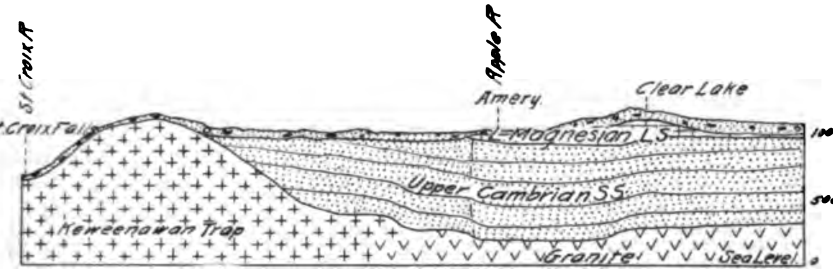

Fig. 59.—Geologic section, Clear Lake to St. Croix Falls, across Polk County.

central and eastern parts. Elevations above sea level vary from 900 feet to 1,200 feet over most of the county. A narrow strip along the bottoms of the St. Croix river below St. Croix Falls is a little less than 700 feet above sea level. The soils are mainly sandy loams and silt loams. A large area of sandy soil lies in the northwestern corner of the county.

GEOLOGICAL FORMATIONS

The geological formations are the Keweenawan trap, the Upper Cambrian sandstone formation, and the Lower Magnesian limestone. The Keweenawn trap ridges extend northeast through the central part of the county. The limestone formation is present only in the southern part of the county. The glacial drift is abundant and is quite generally present, over the entire county. The geological structure is illustrated in the cross section, Fig. 59.

The thickness of the surface formations of glacial drift, and alluvial filling in the valleys, varies between wide limits. The drift is rela-

tively abundant over the entire county, many wells showing a thickness of 100 to 150 feet, the maximum thickness probably reaching 200 to 250 feet in the old valleys and in the morainic ridges. The deposits of lacustrine clays and associated silts and sand in the sandy track in the northwestern part of the county probably reaches a depth of 200 to 250 feet in deepest parts of the filled valley. The thickness of the rock formations is variable on account of the extensive erosion of the strata. The complete thickness of the Upper Cambrian sandstone is preserved only where protected by the overlying Lower Magnesian limestone in the southern part of the county. The surface of the Keweenawan trap, upon which the sandstone rests, is very uneven, and where the trap underlies the sandstone the latter is correspondingly less in thickness.

The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Polk County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Lower Magnesian limestone	0 to 150
Upper Cambrian (Potsdam) sandstone	0 to 800
Pre-Cambrian formations	....

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing beds are mainly the sandstone and the glacial drift. The Keweenawan trap is practically impervious and water is obtained from it only in the open fractures and fissures. The limestone, quite generally much fractured, furnishes abundant water. There are many wells in the surface formation of drift, which are relatively shallow, sufficient water being obtained in open wells at depth of 20 to 40 feet. There are many drilled wells in the southern part of the county, however, that are from 100 to 200 feet deep, which draw their supply from the underlying rock, usually from the Potsdam sandstone or from sandstone beds within the Lower Magnesian formation.

FLOWING WELLS

In the vicinity of Osceola is a local artesian area, in the surface formation, along Osceola Creek. By driving one-half or two-inch pipes

into the ground 15 or 20 feet, good flows of water are obtained. The pipes are driven through 3 to 4 feet of black muck and clay, such as is generally found along meadow brooks, then through 10 to 15 feet of clay, into a bed of gravel and sand, below which the supply of water is obtained in varying quantities. In places these wells are driven only 3 or 4 feet apart. In some of the strongest flows water rises 12 to 15 inches above the mouth of the pipes. The difference in the flow at these wells depends upon the porosity of the gravel beds, and the quantity of water obtained increases as the well pipes are kept open. Some pipes are nearly "choked" and consequently furnish no flows. It is essential, therefore, that the pipes be cleaned and made as open as possible if a strong flow is desired. Water in the underlying sandstone may help supply the artesian pressures. The water, however, is immediately derived from the gravel beds and sands along the sides of the valleys.

Although not extensively developed at present, it seems probable that artesian flows from the sand and gravel horizon may be had throughout the little valley of Osceola Creek, which is about 8 miles long.

Numerous springs and small streams occur all along the St. Croix river at Osceola, for a distance of 15 miles up and down the river, and wherever the clay and muck forms the surface, flowing wells of the above type may be obtained in favorable places, by driving points 10 to 20 feet into the sand and gravel beds.

Gustave Hanson has three flowing wells near Osceola, the supply being derived from the Upper Cambrian sandstone. The first two wells were drilled 175 and 450 feet deep in the shale and sandstone. A third well was drilled on the lowest ground about 200 feet away from the second and just about two feet above the trout ponds. The third well flowed best of the three but took the water from the others. These wells clearly show interference. If the same head is desired, or a flow at the higher well is desired, the flow from the lower one should be partially reduced.

At the trout hatchery of Dr. O'Hage four miles west of Osceola there are between 40 and 50 flowing wells, the pipes being one and one-half to two and a half inches in diameter.

SPRINGS

Springs are mainly confined to low ground along the St. Croix river and along the Apple river. The springs along the St. Croix river, be-

tween St. Croix Falls and Osceola, issue from the sides of the valley, either at the contact of the beds of shale with overlying beds of sandstone, or at the contact of the shale with the overlying drift, or through the openings in the shale or drift anywhere below the shale contact. The springs in St. Croix Falls, and within the area of the Interstate Park, are especially large, and furnish not only a copious supply of

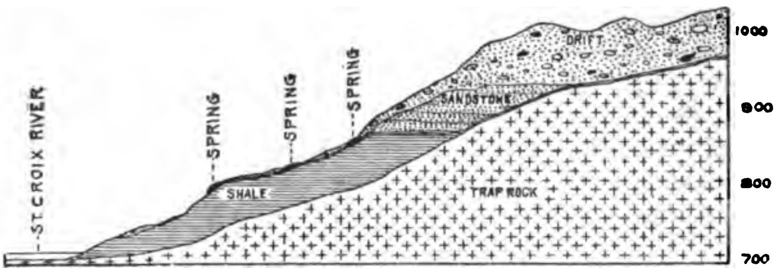

Fig. 60.—Geologic section illustrating the source of the springs at St. Croix Falls.

good clear water for drinking and domestic purposes, but are also utilized to some extent for the development of water power at the flour mill in the village. The source of these springs is indicated in the section, Fig. 60.

The Bethania Mineral Spring, near Osceola, is utilized for the extensive manufacture of soft drinks.

WATER SUPPLIES FOR CITIES AND VILLAGES

St. Croix Falls. St. Croix Falls, located on the St. Croix river, has a population of 569. The city is located on a rather steep slope of the narrow valley, on the Keweenewan trap and Upper Cambrian sandstone formation. In the upper part of the city glacial drift is relatively thick. A city water supply was installed in 1907. The water is obtained from a well about 100 feet deep, curb about 150 feet above the level of the river. The well was drilled about 60 feet into the trap rock, but the main supply of water comes from the contact of the shale beds with the overlying sandstone at depth of about 40 feet. There are many large springs in St. Croix Falls and within the area of the Interstate Park, as described above.

Osceola. Osceola, population 634, is on the St. Croix river at the mouth of Osceola Creek. This village has no public water supply or sewage system. Many of the houses in Osceola are supplied from springs that issue near the river.

Amery. Amery, population 659, is situated on the Apple river. The city water supply is obtained from an 8-inch well, 312 feet deep, 112 feet in drift and 200 feet in the sandstone. The well is cased to the sandstone. Many of the private wells in the city are from 40 to 60 feet deep in sand and gravel.

Luck. This village, population 383, is located on a level tract on Butternut lake. Water is supplied from private wells, dug in sand, gravel and drift, to a depth of 20 to 30 feet generally.

Clear Lake. Clear Lake, population 498, is located on a glacial drift ridge. The private wells are generally from 20 to 60 feet deep in the drift. A public supply was recently installed, being obtained from a well 200 feet deep

Frederick. This village is located on a small lake, Coon Lake, and has a population of 511. The village water supply originally was obtained from a 12-inch well, 120 feet deep, and later the supply was obtained from the lake. The supply at present is obtained from a well dug 5 feet in diameter and 72 feet deep, with 5 well points 12 ft. long driven in sand and gravel at the bottom. The well can be pumped dry in about two hours. Average daily pumpage 10,000 gallons, capacity of reservoir 30,000 gallons. Practically the entire population use the city supply, there being only one private deep well in the city. No sewage system is installed.

The village water supply can be increased, either by drilling the present well deeper, to the trap rock, or by drilling an additional 10 in. or 12 in. well, several hundred feet from the present well.

SALT WATER FLOWING WELL

About 5 miles north of Osceola in Sec. 1, T. 33, R. 19, at the Cooper cottage, a mining exploration shaft for copper ore was sunk under the general management of H. Holbert in 1909. At a depth of 60 feet in this shaft water was struck under pressure, and rose to within 25 feet of the surface. A short distance south of this shaft, on lower ground, a diamond drill hole was sunk to depth of about 700 feet. In this drill hole water under pressure was struck at a depth of about 40 feet and rose a few feet above the surface, developing a flowing well, the water having a strong salty taste.

The composition of this salt water, stated in theoretic combination in grains per gallon, (see also table of analyses) is as follows:

Analysis of Salt Water, 5 miles north of Osceola.*

In grains per gallon.

Calcium chloride	583.10
Sodium chloride	320.58
Magnesium chloride	18.98
Calcium sulphate	62.20
Silica	6.07
Ferric-oxide and Alumina	2.97
Total	993.90

*Analysis by J. H. Long, for H. Holbert.

The formations penetrated in this deep well are a few feet of glacial drift, followed by sandstone, and sandstone conglomerate containing trap boulders, to depth of 95 feet. At 95 feet relatively massive Keweenawan trap rock is struck, from which probably very little or no water is obtained. The source of the salt water, therefore, is in the flow obtained at depth of 40 to 90 feet, overlying the Keweenawan trap.

Conditions favorable to the developing of flows at this place are due to the occurrence of relatively impervious shale beds within the sandstone formation overlying and interbedded with porous conglomerate at the contact of the underlying Keweenawan formation.

Water from a depth of 50 feet in the nearby exploration shaft was analyzed and showed a mineral content of 1,457 parts per million, mainly sulphates, while the water at only slightly greater depth in the drill hole (mainly within depth of 95 feet) had a mineral content of 16,995 parts per million, the increase in amount being chlorides of calcium and sodium.

The most important constituents of the salt water are chlorides of calcium and sodium. The high content of mineral matter is unusual. The source of the mineralization is not understood. It is a noteworthy fact that the Keweenawan trap and associated red sandstone formations in the Lake Superior region often contain waters highly charged with calcium chloride salts. This is true in deep mine waters of the Keweenawan copper-bearing rocks of northern Michigan, as shown by Dr. A. C. Lane.[1] It is possible, therefore, that other occurrences of highly mineralized waters in the Keweenawan and associated strata may be found.

[1] Lake Superior Mining Inst. Vol. XIII, p. 63–152.

QUALITY OF THE WATER

With the notable exception of the highly mineralized water (salt water) above described, the water of Polk county is only moderately mineralized. In the area of outcrop of the limestone in the southern part of the county, the water probably is quite generally a hard water, though of only moderate mineral content, as shown by the Bethania Spring waters, No. 1, in the table of analyses below. The water from the Bethania Springs is used for the manufacture of soft drinks.

Mineral analyses of water in Polk County.

(Analyses in parts per million)

	Springs.				Upper Cambrian Sandstone.	
	1.	2.	3.	4.	5.	6.
Depth of well ....feet..					50	700
Silica (SiO_2)	8.7	4.5	8.0	9.0		103.
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)		8.4	trace	trace	152.7	50.7
Aluminium oxide (Al_2O_3)	1.3				24.5	
Iron (Fe)	0.8					
Calcium (Ca)	70.5	47 4	40.2	46.6	315.0	3912.7
Magnesium (Mg)	28.8	20.6	13.0	14.5	13.1	82.7
Sodium (Na) Potassium (K)	81.9	7.0	trace	trace	50.4 19.7	2154.
Carbonate radicle (CO_3)	185.8	126.5	82.4	95.6	98.9	
Sulphate radicle (SO_4)	15.6	6.1	16.4	16.1	788.2	750.9
Chlorine (Cl)	37.8	0 5	trace	trace		9040.7
Organic matter		trace				
Nitrate radicle			trace	trace		
Total dissolved solids	379.	221.	160.	181.8	1457.	16995.

1. Bethania Spring at Osceola.
2. St. Croix Minerol Spring at Osceolo, Analyst, J. V. Z. Blaney, Geol. of Wis., Vol. III, p. 374, 1879.
3. Spring of H. Holbert, 5 miles north of Osceola, Analyst, H. C. Carel, May 1900.
4. Spring of H. Holbert, 3 miles north of Osceola, Analyst, H. C. Carel, May 1900.
5. Well, (Exploration shaft) of H. Holbert, 5 miles north of Osceola, Analyst, L. A. Harding.
6. Exploration drill hole, flowing well, 5 miles north of Osceola, Analyst, J. H. Long, Dec. 1901 (water from sandstone at depth of 40 to 90 feet).

PORTAGE COUNTY

Portage county, located in the central part of the state, has an area of 800 square miles, and a population of 30,945. About 79.1 per cent of the county is laid out in farms, of which 53 per cent is under cultivation.

SURFACE FEATURES

The northwestern part of the county is a gently undulating upland plain. The eastern part, traversed by the glacial moraines, is quite choppy and uneven. The southwestern part is a broad level alluvial

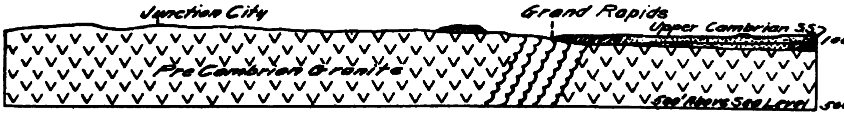

Fig. 61.—Geologic section, north-south, along the boundary of Portage and Wood counties.

plain. The valley of the Wisconsin river is a relatively deep trench running south through the central portion. Elevations of the surface generally range between 1,000 feet along the Wisconsin river to 1,200 feet above sea level on the uplands. The soils vary from sand to silt loams, the lighter soils occurring along the rivers and over the broad low-lying plain of the southwestern part of the county.

GEOLOGICAL FORMATIONS

The rock formations are the Pre-Cambrian crystallines and the Upper Cambrian (Potsdam) sandstone, the former exposed in the northern part of the county and along the Wisconsin river, and the latter, mainly in the southern part of the county. Relatively thick drift in prominent ridges occurs over the sandstone and crystallines in the eastern part of the county. Alluvial sand and gravel forms a thick deposit along the Wisconsin river and extends over the broad plain of the southwestern part of the county. The geological formations are illustrated in the cross section, Fig 61.

The thickness of the surface formations is quite variable and probably reaches a maximum of 200 to 250 feet in the valleys. The thickness of the sandstone is also quite variable on account of the extensive erosion

of the strata. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Portage County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Upper Cambrian (Potsdam) sandstone	0 to 400
The Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

The groundwater supplies are derived from all the geologic formations. The wells in the crystalline rock are relatively shallow, but in the porous gravel, drift and sandstone formations, wells have to be sunk to a common water level, and hence, where the land is uneven or undulating, wells are much deeper than on the flat areas bordering the rivers and streams.

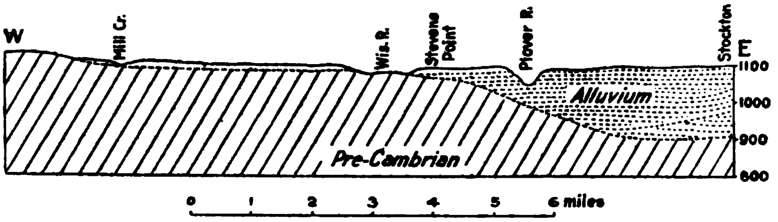

Fig. 62.—Geologic section of the vicinity of Stevens Point showing relations of the alluvial sand and gravel to the Pre-Cambrian crystalline rocks.

WATER SUPPLIES FOR CITIES AND VILLAGES

Stevens Point. Stevens Point, with a population of 8,692, is located on the Wisconsin river, at the site of extensive water power. Crystalline rock, such as granite and schist, make the rapids. Only a thin covering of alluvial sand and gravel, from 5 to 10 feet generally lies upon the granite in the western portion of the city. To the east the sand and gravel deepens. See Fig. 62. The sandstone outcrops in the southern and western part of the city. Most of the private wells are shallow, from 10 to 20 feet deep.

The city water supply is taken partly from the Wisconsin river, and partly from two open wells, near the river, 50 and 60 feet in diameter, and 33 feet in depth. The river water is taken from 3 to 6 feet below

the surface, depending on the low or high water stage of the river. The river water is filtered. The average pumpage is about 652,000 gallons per day. An abundant supply of good water, by a proper system of wells, could be obtained for this city from the thick gravel and sand formation, a short distance to the east or northeast of the city. About one-half of the houses have water connections, and about one-third are on the sewage system. The sewage is emptied, without treatment, into the Wisconsin river.

Amherst. Amherst, population 629, is located on the Waupaca river, on sandy loam drift hills overlying the sandstone rock. Abundant water is obtained from depths of 20 to 60 feet, depending upon elevation above the river. A water supply system is installed for fire purposes only, river water being used which is obtained from the flour mills.

Almond. Almond is located upon a sandy plain of alluvial and glacial origin. Wells in Almond are from 50 to 70 feet deep in the gravel and sand.

At Amherst Junction wells are from 40 to 70 feet in drift. At Nelsonville wells vary from 20 to 50 feet in drift. At Rosholt wells are from 14 to 25 feet in drift.

In Plover many of the wells are from 16 to 20 feet deep in the alluvial gravel and sand. In Bancroft the wells are from 12 to 20 feet in gravel and sand, with the exception of the C. & N. W. R. R. well, which is 90 feet deep in gravel and sand. In Custer the wells are usually from 40 to 50 feet in gravel and sand. In Arnott and locality the wells are from 50 to 75 feet deep in gravel and drift.

QUALITY OF THE WATER

The mineral analyses of railroad water supplies at Rosholt, Bancroft and Junction City, are shown in the following table. The waters are hard waters of moderate mineral content. The water at Junction City is a sulphate water, while the others are carbonate waters. The "Soo" railroad well at Bancroft, of shallow depth, 13 feet, contained a relatively high content of sulphates, while at greater depth, 98 feet, the C. & N. W. railroad well at Bancroft, contained only a small amount of sulphates. The groundwaters throughout the county are likely to be of moderate mineral content and very much the same as those quoted in the above table.

The water from the well at Rosholt, No. 1, contains 1.45 pounds of incrusting solids in 1,000 gallons, and that from the well at Bancroft, No. 3, contains 1.66 pounds in 1,000 gallons.

Mineral analyses of water in Portage County.

(Analyses in parts per million)

	Surface deposits (alluvial sand).			Pre-Cambrian Granite Rock.			
	1.	2.	3.	4.	5.	6.	7.
Depth of well..........feet..	15	13	98	80	80	80	?
Silica (SiO_2).....................	10.9	11.3	11.9				
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)..........	1.7	0.5	1.0	6.8	4.0	undet.	15.8
Calcium (Ca)..................	35.4	38.0	43.6	43.1	18.7	32.4	28.5
Magnesium (Mg)............	18.6	18.2	21.8	24.4	11.1	19.6	0.0
Sodium and potassium (Na+K).....................	1.3	3.8	5.0	9.8	7.3	10.7	1.8
Carbonate radicle (CO_3)....	92.9	68.5	119.9	41.1	53.5	49.5	41.7
Sulphate radicle (SO_4)......	11.9	61.4	3.8	150.0	13.6	81.9	1.3
Chlorine (Cl)................	2.0	5.9	4.1	3.5	3.0	4.0	2.8
Total dissolved solids........	175.	208.	211.	279.	111.	198.	92.

1. Well of C. & N. W. Ry. at Rosholt, Analyst, G. M. Davidson, Oct. 9, 1909.
2. Well of "Soo Railroad" at Bancroft, Analyst, G. M. Davidson, Mar. 18, 1901.
3. Well of C. & N. W. Railroad at Bancroft, Analyst, G. M. Davidson, Sept. 30, 1901.
4. Well of C. M. & St. P. Ry. Co. at Junction City, Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 7, 1896.
5. Well of C. M. & St. P. Ry. Co., Junction City, Analyst, Chemist C. M. & St. P. Ry. Co., Aug. 6, 1892.
6. Well of C. M. & St. P. Ry. Co., Junction City, Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 23, 1896.
7. Well at Junction City, Analyst, Chemist, C. M. & St. P. Ry. Co., July 26, 1886.

PRICE COUNTY

Price county, located in the north central part of the state, has an area of 1,341 square miles, and a population of 13,795. About 14.5 per cent of the county is in farms, of which 19.4 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is mainly a gently sloping plain. There are some prominent drift hills in the vicinity of Ogema, and farther east, and also in the region southwest of Phillips. The land surface slopes to the southwest, the principal drainage lines being the Flambeau and Jump rivers. Small lakes and marshes are common. The soils are generally heavy silt loams, with a varying amount of sandy and gravelly loam.

The altitudes generally range between 1,400 and 1,650 feet, with some high points in the hilly portions probably reaching up to over 1,900 feet.

GEOLOGICAL FORMATIONS

The geological formation is mainly glacial drift, which quite generally covers the hard rock formations. The granite rocks occur only along the river bottoms, where rapids and falls are usually developed. The thickness of the drift is usually between 50 and 100 feet, the maximum thickness probably being 200 to 250 feet. For geologic section, see Fig. 23.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons is the surface formation of glacial drift. An abundant supply is readily obtained in the drift at relatively shallow depths of 20 to 40 feet.

In Catawba the ground water level is about 20 feet below the surface. The well at the Catawba saw mill is 79 feet deep in drift. In Kennan, wells are generally from 15 to 30 feet deep. At the Kennan saw mill the well is 130 feet deep, with sandstone reported at bottom. The railroad well at Pennington is 27 feet deep in drift. The deepest well reported about Pennington is 33 feet deep. The wells in Prentice are generally from 30 to 40 feet in glacial drift. Ogema, located in hilly terminal moraine, has wells varying in depth up to about 100 feet.

WATER SUPPLIES FOR CITIES AND VILLAGES

Phillips. Phillips, the county seat, has a population of 1,948. The city is located on the Little Elk river, a tributary of the Flambeau. The elevation of the railroad station is 1,454 feet. The city is located on low undulating hills of drift. The city has a system of waterworks for fire protection, the water supply being taken from the river. Most of the water for drinking purposes is derived from about 50 wells, with a varying depth of 10 to 80 feet in drift. The sewage system, partially developed, has its outlet into the river.

Park Falls. Park Falls, a city of 1,972, population, is located at the site of water power on the Flambeau river. The elevation of the railroad station is 1,492 feet. The city is located on uneven drift hills, with clay loam surface soil and sandy gravelly subsoil. The private

wells are usually from 15 to 25 feet deep. The public water supply, used mainly for fire protection, is obtained from the river. A good groundwater supply could readily be obtained. A sewage system was recently installed on the main streets, with outlet into the river.

Fifield. This village is located on the south fork of the Flambeau river. The water supply is derived from wells 12 to 40 feet in gravel and sand of the glacial drift formation.

THE QUALITY OF THE WATER

No complete analyses of the water supplies of Price county are at hand, but judging from the partial analyses available and the shallow depth of the water-bearing formations the water is very probably soft water, with a relatively low content of mineralization.

The partial analyses of water supplies used by the M. St. P. & S. S. M. Ry. Co. in which analyses the sodium and potassium carbonates, the calcium and magnesium carbonates, the calcium and magnesium sulphates, the sodium chloride, and iron and alkali salts, are determined, are stated in total grains per gallon and total parts per million in the following table:

Partial mineral Analyses of Water in Price County.

Station.	Dissolved solids gr. per gallon.	Dissolved solids parts per million.
Ogema	7.27	124
Worcester	10.45	179
Phillips	4.87	75
Fifield	3.28	56

RACINE COUNTY

Racine county, located in the southeastern part of the state, has an area of 323 square miles and a population of 57,424. About 96.2 per cent of the county is in farms of which 73.9 per cent is under cultivation.

SURFACE FEATURES

The surface of Racine county is a gently undulating plain sloping eastward toward Lake Michigan. The valleys which are broad and shallow and the upland ridges which are gently sloping generally trend north and south parallel to the shore of Lake Michigan. The eastern part of the county is drained by the Root river flowing to Lake Michigan and the western part is drained by the Fox river (of Illinois) flowing southwest to the Mississippi.

The altitude of Lake Michigan on the eastern boundary is 581 feet, and of the valley bottom of the Fox in the western part about 740 to 760 feet. The broad uplands in the eastern part rarely exceed an altitude of 740 feet, and the highest point in the western part located west of the Fox river, is about 940 feet. The usual difference in elevation between valley bottom and adjacent uplands is therefore less than 150 feet, the maximum difference being 200 feet.

GEOLOGICAL FORMATIONS

The surface deposits of glacial drift and associated alluvial and lacustrine deposits form a general covering over the indurated rock formations. The rock formation immediately underlying the surface deposits is the Niagara limestone formation. (See geological section, figure 44).

The drift and associated surface deposits are of variable thickness, the known maximum thickness in the county in the well at Union Grove being 195 feet. It is quite probable, however, that the thickness of the surface deposits is much greater than this in various places in the county. The thickness of the surface deposits in the city of Racine does not appear to exceed 100 to 125 feet, and at Burlington 50 or 60 feet. The usual range in thickness of the drift is between 25 and 100 feet.

The thickness of the Niagara is also variable on account of the unequal erosion of this formation. The known thickness as shown by well records ranges between 120 and 350 feet. The minimum thickness is probably not much less than 100 feet, and the maximum thickness probably not more than 500 feet.

The probable range in thickness of the formations in Racine county, may be summarized as follows:

Range in thickness of formations in Racine County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone	100 to 500
Cincinnati shale	140 to 200
Galena-Platteville (Trenton) limestone	250 to 350
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	800 to 1000
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

All of the geological formations from the surface deposits overlying the Niagara down to the Upper Cambrian (Potsdam) sandstone are drawn upon for water supplies. The principal water-bearing horizons, however, for shallow wells are the Niagara limestone and the glacial drift. Only in the deep artesian wells are the St. Peter sandstone and the Upper Cambrian sandstone horizons drawn upon.

The water level throughout the county is generally only a short distance below surface, being within 10 to 20 feet of the surface in the valleys and very generally less than 100 feet below the surface on the gentle slopes of the upland areas. In surface wells abundant water can generally be obtained within the drift, or at the contact with the underlying limestone or a short distance into the limestone.

FLOWING WELLS

Flowing wells in the surface deposits and in the underlying rock occur in various parts of the county. The shallow flowing wells are from the drift or from the upper surface of the Niagara limestone underlying the drift. Near Racine, this glacial drift or limestone horizon has furnished many flows, the depth of the wells ranging from 30 to 104 feet.

The rise of the surface toward the west soon prevents a flow from being obtained but on low ground flows may be expected over a very wide area, while on higher ground non-flowing artesian water from the same source may be obtained. Surface flows from the drift also occur at Union Grove and Yorkville at depth of 60 feet, and many at Caledonia at 50 to 100 feet and in Burlington at 30 to 60 feet.

Deep seated flows from the rock formations underlying the Niagara limestone and Cincinnati shale mainly from the sandstone of the St. Peter, and the Upper Cambrian (Potsdam) horizons also occur in various parts of the county. The underground water in all the deep seated formations is under pressure and where the artesian reservoir is tapped by deep wells, the water will rise above the surface of the curb if the altitude of the surface is not too great.

In Racine county there are 12 deep artesian flowing wells from 1,200 to 1,742 feet deep that have a head at various elevations up to 80 feet above the level of Lake Michigan. At Corliss is a flowing well, 1,263 feet deep with head 40 feet above the surface, or 185 feet above Lake Michigan. At Burlington, the city well 1,008 feet deep, has a head 30 feet above the surface or about 215 feet above Lake Michigan. The normal head therefore rises up the slope of the strata as the distance from the lake increases, so that deep artesian flowing wells are possible in the eastern part of the county along the Lake at altitudes up to 660 feet, and in the western part along Fox river at altitudes up to 795 feet, with head between these altitudes at intermediate points. Altitudes sufficiently low for development of flows therefor occur only on relatively low ground along the lower slopes of the valleys.

WATER SUPPLIES FOR CITIES AND VILLAGES

Racine. Racine, located on Lake Michigan at the mouth of Root river, has a population of 38,002. The city water supply is obtained from Lake Michigan from one intake at depth of 47 feet. The sewage, without purification, is drained into Root river and Lake Michigan. About 95 per cent of the houses are connected with the water supply, and about 50 or 60 per cent have sewer connections. The average daily pumpage at the waterworks is a little over 3,400,000 gallons.

There are many artesian wells in Racine. No very marked interference has been noted because many of these wells are not very close together. The artesian reservoir has not been overtaxed and new wells have approximately the same pressure as the wells drilled some time ago. The difference in head is partly due to elevation and partly to im-

proper casing, as at Milwaukee. The wells here sometimes fail to flow as the water escapes through leaks at lower levels. There are four artesian water horizons,—the drift, the Niagara limestone, the St. Peter sandstone, and the Upper Cambrian (Potsdam) sandstone, and the flow usually increases with each succeeding horizon as the well is drilled deeper. There are at least 14 deep artesian wells in Racine, from 1,200 to over 2,000 feet deep, that flow at various elevations up to 80 or 90 feet above the level of the lake.

Logs of artesian wells in Racine.

Location.	Drift.	Niagara lime-stone.	Cincin-nati shale.	Galena-Platte-ville lime-stone.	St. Peter sand-stone.	Lower Magnes-ian lime-stone.	Upper Cam-brian (Pots-dam) sand-stone.	Total.
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Lakeside	124	300	130	340	100	160	396	1550
Ives Corners	2	300	200	325	60	....	622	1509
Racine College	115	305	185	283	48	100	204	1240
John Fox	....	225	275	350	....	....	650	1500

The log of the Racine College well recorded in Geology of Wisconsin, Vol. 2, p. 163, is of interest since it records the Mendota limestone, which may be the same as the lowest limestone struck at Milwaukee. Of the 204 feet of Potsdam sandstone in the Racine College well, 47 feet is Madison sandstone, 31 feet Mendota limestone, 110 feet red sandstone, 10 feet hard sandstone, and 6 feet of soft sandstone.

Two deep flowing wells were recently drilled at the plant of the Horlick Malted Milk Co. Samples of the formations taken every 10 feet were kindly furnished by the owners, and are now on file in the office of the State Survey. The wells are locatd in Sec. 6, T. 3 R. 23 E., the elevation of the curb of well No. 1 being 645 and of well No. 2, 647 feet. The sections of the two wells, as interpreted by F. T. Thwaites, are as follows:

Logs of Horlick Malted Milk Co.'s Wells, Racine.

Formation.	Well No. 1. thickness.	Well No. 2. thickness.
	Feet.	Feet.
Pleistocene:		
Gray calcareous clay	100	95
Niagara:		
Gray dolomitic limestone, with a red limestone near the middle and shaley towards the base	350	335
Cincinnati:		
Calcareous gray shale	140	160
Galena-Platteville:		
Gray magnesian limestone showing a thin sandy layer near base in Well No. 1	315	310
St. Peter:		
Fine-grained calcareous sandstone with shaley layers	70	85
Lower Magnesian:		
Gray sandy dolomite, some layers very sandy	90	80
Upper Cambrian (Potsdam):		
Pink and white, or brown, calcareous sandstone with 40 to 50 feet of red calcareous shale about 200 feet from the top	945	635
Total depth	2,010	1,700

Burlington. The city of Burlington, located on Fox River, has a population of 3,212. The city has a water supply obtained from three artesian wells. About 75 per cent of the houses are connected with the water system. The average daily pumpage is 211,000 gallons. A sewage system was recently installed providing for treatment of the sewage before its discharge into the Fox river.

The city has drilled three wells for the waterworks plant,—one 8 inches in diameter and 1,008 feet deep, one 6 inches in diameter and 600 feet deep, and one 155 feet deep. The deep wells flowed above surface four years and then ceased.

The section of the 1008 foot well is as follows:

Log of Burlington City Well.

Formation.	Thickness.
	Feet.
Gravel	24
Niagara limestone	180
Cincinnati shale	200
Galena-Platteville limestone	20
St. Peter sandstone	100
Upper Cambrian (Potsdam) sandstone	484
Total depth	1,008

The log of this well shows a small thickness of the Galena-Platteville limestone. It is of interest, however, to compare this log with that of the deep well at Union Grove, as the *combined* thickness of the Cincinnati shale and the Galena-Platteville in the two wells is reported to be about equal.

There are many private wells in Burlington that obtain their supply from Niagara limestone 50 to 150 feet deep.

Union Grove. Union Grove, population 616, has a municipal water supply obtained from a well 287 feet deep. The daily pumpage is 25,000 gallons. Most of the houses are connected with the water supply. In the village of Union Grove is a well 2,005 feet deep, having the following section as reported to Dr. W. C. Alden of the U. S. Geological survey.

Log of Union Grove Well.

Formation.	Thickness.
Pleistocene.	Feet.
Drift	195
Niagara.	
Limestone	120
Cincinnati.	
Blue and green shale	52
Galena-Platteville.	
Limestone	180
St. Peter.	
Sandstone	200
Upper Cambrian (Potsdam).	
Colored beds of sandstone, alternating with beds of red marly rock: near bottom sandstone becomes coarse and cuts easily	1,258
Total depth	2,005

It is of interest to compare the log of this well with logs of the Horlick wells at Racine, that of the wells at Corliss, and that of Herman Krender at Somers, in Kenosha county, as well as that of the Burlington city well.

Corliss. In the village of Corliss are two deep wells of special interest. The first deep well at this place was drilled by the Chicago, Milwaukee, and St. Paul Railway Company in 1875. The log given in Geology of Wisconsin, Vol. 2, p. 163 is as follows:—

Log of C. M. & St. P. Rw. well at Corliss.

Formation.	Thickness.
	Feet.
Pleistocene.	
Drift	147
Niagara.	
Limestone	288
Cincinnati.	
Shale	200
Galena-Trenton.	
Limestone	285
St. Peter.	
Sandstone	100
Lower Magnesian.	
Limestone	141
Potsdam.	
Sandstone	157
Total	1,263

The record states that 15 feet of limestone was passed through in the Potsdam sandstone, but the depth of the limestone is not given. The altitude of the curb is 765 feet, and the original head was 40 feet above the curb. In 1899 the water stood below the surface and had to be pumped. An artesian well has been drilled at this place 1,507 feet deep for the Corliss Machinery Co. The village has a public supply furnished by the Wisconsin Engine Co.

QUALITY OF THE WATER

The mineral analyses of various water supplies of Racine county are shown in the following table. The water from Lake Michigan is of low mineral content, though it should be classed as medium hard. The waters analyzed from the surface deposits and underlying rock, are either moderate or high in mineral content. Only a few of the waters, however, are very hard waters on account of the fact that much of the mineral salts are alkali sulphates. Both sulphate and carbonate waters occur. The sulphate waters occur in relatively shallow wells, in the flowing well at Willow, and also in the deep wells at Racine Junction and Racine. All the waters are calcium and magnesian waters, except the flowing well at Willow, No. 6, and the Wisconsin Eng. Co's. well at Corliss, No. 10, which are sodium waters. The high sodium and potassium in the water of these two wells is similar to the high sodium water at Bain, Bristol, etc., in Kenosha county, from the same horizons.

The water from Lake Michigan, No. 2, contains 1.01 pounds of incrusting solids in 1,000 gallons; that from Root river, No. 1, contains 2.84 pounds in 1,000 gallons; that from the artesian well at Racine Junction, No. 13, contains 3.69 pounds in 1,000 gallons, and that from the flowing well at Willow, No. 6, high in sodium and potassium, contains only 2.71 pounds in 1,000 gallons.

The deep well waters at Racine do not appear to be so highly mineralized as those at Milwaukee. The quality of the waters throughout the county is likely to be very similar to those shown in the table, as waters from all the formations are included in the table.

Mineral analyses of water in Racine County.

(Analyses in parts per million)

	River.	Lake.	Surface deposits.			
	1.	2.	3.	4.	5.	6.
Depth of well....feet..	....	....	12	26	40	114
Silica (SiO_2)........	9.9	2.1	2.9	3.8	0.8	20.3
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)........	....	1.2	....	....	....	1.2
Calcium (Ca)........	74.7	30.7	77.5	70.1	81.7	38.8
Magnesium (Mg)........	38.6	10.7	33.1	36.5	35.2	30.8
Sodium (Na)........ Potassium (K)........	18.6	5.6	9.9	8.0	10.3	115.4
Carbonate radicle (CO_3)........	169.6	66.3	174.0	175.5	165.9	36.1
Sulphate radicle (SO_4)........	56.1	12.2	54.0	40.0	78.4	418.5
Chlorine (Cl)........	7.9	7.0	2.7	5.2	7.2	7.5
Organic matter........	....	Trace.	....	....	....	....
Total dissolved solids........	395.	136.	354.	339.	380.	669.

	Niagara limestone.				St. Peter and Upper Cambrian (Potsdam) sandstone.		
	7.	8.	9.	10.	11.	12.	13.
Depth of well....feet..	130	180	130	300	1008	1000	1400
Silica (SiO_2)........	6.7	7.8	1.4	undt.	6.6	....	19.3
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)........	....	....	....	....	....	1.9	....
Aluminium oxide (Al_2O_3)..	0.4	....	....	....	0.5	....	1.5
Iron (Fe)........	0.1	....	....	....	1.5	....	....
Calcium (Ca)........	63.5	125.0	58.1	59.5	63.4	65.2	111.0
Magnesium (Mg)........	25.2	35.0	39.6	27.9	25.2	26.7	25.7
Sodium (Na)........	9.0	73.6	52.8	99.4	9.0	11.5	43.8
Potassium (K)........	4.2				4.1		
Carbonate radicle (CO_3)...	139.1	159.7	105.8	45.0	139.1	144.1	158.9
Sulphate radicle (SO_4)......	47.4	300.7	205.0	373.3	47.1	48.2	177.7
Chlorine (Cl)........	4.7	26.3	11.8	10.1	4.7	4.3	28.9
Total dissolved solids..	300.	728.	470.	615.	300.	302.	567.

1. Root River at Racine, Analyst, G. M. Davidson, Feb. 1892.
2. Lake Michigan, City Water Supply of Racine, Analyst, Dearborn Drug & Co., Mar. 8, 1911.
3. Well of C. M. & St. P. Ry. Co., Burlington, Analyst, Chemist C. M. & St. P. Ry. Co., April 10, 1891.
4. Well of C. M. & St. P. Ry. Co., Burlington, Analyst, Chemist C. M. & St. P. Ry. Co., Mar. 19, 1899.
5. Well of six tubular wells of C. M. & St. P. Ry. Co., Burlington, Analyst, Chemist, C. M. & St. P. Ry. Co., July 27, 1897.
6. Well of C. & N. W. Ry. Co. near section house Willow, Analyst, G. M. Davidson, Feb. 1906.
7. Well of Mc Cona & Fraser, Burlington, flowing well, Analyst, E. G. Smith.
8. Well of C. M. & St. P. Ry. Co., Union Grove, Analyst, Chemist, C. M. & St. P. Ry. Co., April 9, 1891.
9. Well of C. M. & St. P. Ry. Co., Union Grove, Anolyst, Chemist, C. M. & St. P. Ry. Co., July 1, 1888.
10. Well of Wis. Eng. Co., Corliss, Analyst, G. N. Prentiss, April 18, 1908.
11. Well of City Water Supply, Burlington, Analyst, E. G. Smith.
12. City well, Burlington, Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 26, 1891.
13. Artesian well of C. & N. W. Ry. Co., Racine Junction, Analyst, G. M. Davidson, June 23, 1891.

Mineral analyses of water in Racine County—Continued.

	St. Peter and Upper Cambrian (Potsdam) Sandstones.						
	14.	15.	16.	17.	18.	19.	20.
Depth of well.........feet..	1500	1500	1500	1500	1500	1500	1500
Silica (SiO_2) .... Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	Undt.	Undt.	Undt.	Undt.	Undt.	Undt.	[illegible]
Calcium (Ca)................	108.5	92.0	90.4	87.2	89.3	91.3	94.2
Magnesium (Mg)...........	22.5	23.7	22.8	22.5	22.5	22.5	20.2
Sodium (Na)............... Potassium (K).............	31.6	58.5	64.2	164.0	64.7	71.8	33.6
Carbonate radicle (CO_3)....	158.0	118.4	122.5	226.2	114.6	131.5	102.7
Sulphate radicle (SO_4)......	151.6	130.	228.6	13.3	236.9	228.2	200.5
Chlorine (Cl)................	7.6	12.0	12.0	11.2	12.3	11.2	8.7
Total dissolved solids...	480.	435.	541.	524.	540.	557.	477.

	St. Peter and Upper Cambrian (Potsdam) sandstone.						
	21.	21.	23.	24.	25.	26.	27.
Depth of well.........Feet..	1654	1654	1654	1507	1507&1654	1600	2005
Silica (SiO_2) .... Aluminium and iron oxides ($Al_2O_3+FeO_3$)............	1.2	2.6	1.2	Undt.	Undt.	13.8	2.7
Aluminium oxide (Al_2O_3)..	....	....	....	....	....	1.0	....
Iron (Fe).....................	....	....	....	....	....	0.9	....
Calcium (Ca)................	133.7	142.0	128.9	108.2	119.0	80.3	117.2
Magnesium (Mg)............	18.2	18.2	19.7	21.6	21.0	15.0	16.4
Sodium and potassium (Na+K)...................	20.3	19.9	19.7	25.2	26.6	43.9	8.8
Carbonate radicle (CO_3)....	166.4	163.5	167.4	162.0	162.1	117.	156.2
Sulphate radicle (SO_4)......	160.5	180.4	152.3	137.7	163.6	151.8	112.5
Chlorine (Cl)................	5.5	6.1	5.6	Undt.	Undt.	4.5	6.2
Total dissolved solids...	506.	533.	495.	455.	492.	428.	420.

14. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, G. N. Prentiss, Mar. 21, 1903.
15. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, G. N. Prentiss, Oct. 20, 1905.
16. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, G. N. Prentiss, Jan. 11, 1906.
17. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, G. N. Prentiss, Mar. 20, 1907.
18. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, G. N. Prentiss, April 18, 1908.
19. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, G. N. Prentiss, July 25, 1908.
20. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, G. N. Prentiss, Feb. 3, 1909.
21. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 17, 1890.
22. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 12, 1894.
23. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 13, 1898.
24. Well of C. M. & St. P. Ry. Co., Corliss, Analyst, Chemist, C. M. & St. P. Ry. Co., Co., Dec. 7, 1899.
25. Two wells of C. M. & St. P. Ry. Co., Corliss, Analyst, Chemist C. M. & St. P. Ry.
26. Well of Racine Well Co., Racine, Analyst, G. Bode.
27. Well of City Water Supply, Union Grove, Analyst, Chemist C. M. & St. P. Ry. Co., July 2, 1888.

Richland County

Richland county, located in the southwestern part of the state, has an area of 576 square miles, and a population of 18,809. About 95.9 per cent of the county is in farms, of which 52.3 per cent is under cultivation.

SURFACE FEATURES

The greater part of the county consists of deeply dissected uplands with a large proportion of sloping land and only a small proportion of level topped upland areas. Level bottom land lies along the Wisconsin river and for some distance up the Pine river and other tributary streams. The valley bottom of the Pine is relatively narrow, being

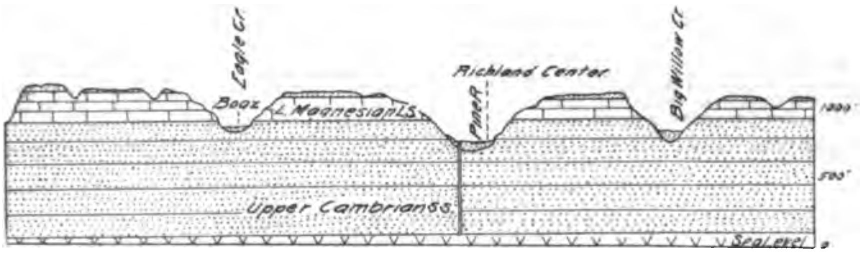

Fig. 63.—Geologic section, east-west, across Richland County.

about 2 miles wide at its mouth and less than a mile wide north of Richland Center. The bottom land along the Wisconsin river has an altitude of about 700 feet, while that along the Pine ranges from 700 feet up to about 800 feet at Hub City. The dissected uplands reach altitudes of 1,100 to 1,300 feet.

The soils in the valleys are generally sand, sandy loams and some silt loams, while upon the upland slopes are quite generally heavier silty loams.

GEOLOGICAL FORMATIONS

The geological formations outcropping in this county are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, and the St. Peter sandstone. The Upper Cambrian (Potsdam) sandstone occurs in the lowest parts of the valleys, the Lower Magnesian forms the main upland areas, and the St. Peter occurs only in small areas on the limestone uplands in the western half of the county. In the

valleys is a variable thickness of alluvial sand overlying the bed rock and upon the uplands are the surface deposits of loess. The geological structure is illustrated in Fig. 63.

The thickness of the alluvial deposits of sand and silt in the valleys probably reaches a maximum of 200 to 300 along the Wisconsin river and in the lower portion of the Pine valley. The thickness of the rock formations is variable on account of the erosion of the strata. The complete thickness of the sandstone is preserved only where protected by the overlying Lower Magnesian limestone formation. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Richland County.

Formation.	Thickness.
	Feet.
Surface	0 to 300
Lower Magnesian limestone	0 to 200
Upper Cambrian (Potsdam) sandstone	500 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The water supply is obtained from all the geological horizons, the principal source being the Upper Cambrian sandstone. The wells upon the uplands find a sufficient supply in the limestone, in the western part of the county, but elsewhere the deeper wells penetrate to the underlying sandstone. An abundant supply is obtained from the shallow wells in the alluvial sand of the valleys. Shallow wells on the uplands where the St. Peter sandstone is present or where the loess has an appreciable thickness furnish a supply sufficient for domestic purposes. The deepest wells on the limestone uplands vary from 100 to 400 feet in depth.

FLOWING WELLS

The altitude of the land surface may be too high to obtain artesian flows from the rock strata. However, occasionally along the valley bottoms flows may be obtainable from the surface deposits of sand underlying clay or silt or from the sandstone. Some sections of the Pine river valley, above Richland Center may develop artesian flows and should be prospected for this purpose.

SPRINGS

Springs are quite common in Richland county along the lower slopes of the valleys. Springs are usually developed where shale strata outcrops along the sides of the valleys. Many of the springs are the source of the permanent streams and furnish an abundance of cold, clear water for domestic use.

WATER SUPPLIES FOR CITIES AND VILLAGES

Richland Center. This city, the county seat, has a population of 2,652. It is situated on the Pine river in an alluvial filled valley in the Upper Cambrian (Potsdam) sandstone. The city has a water supply and sewage system. The average daily pumpage is 250,000 gallons. Sewage is emptied, without treatment, into Pine river. About 75 per cent of the families have water and sewer service. The city water supply was formerly obtained from a 6-inch well, 748 feet deep, 98 feet in alluvial sand, and 650 feet in the Potsdam sandstone and granite. Recently a new well was drilled for the city supply, which struck the granite at 665 feet. The elevation of the well curb is about the same as the railroad station, 736 feet above sea level.

Viola. Viola, population 671, located on the line between Richland and Vernon counties, has a municipal water supply, obtained from a 6-inch artesian well about 500 feet deep. About 74 houses connect with the water supply. A sewage system is installed, the sewage being emptied, without purification, into the Kickapoo river. About 32 houses connect with the sewage system.

QUALITY OF THE WATER

Only two mineral analyses of the water of Richland county are available. Both of the waters analyzed are from shallow wells in the surface deposits of alluvial sand. Both are hard waters of moderate mineral content. The large amount of chlorine in the samples analyzed indicates contamination from surface groundwaters. The water supplies drawn from the limestone formation, as well as that from the Potsdam sandstone throughout the county, are likely to be somewhat higher in mineral content than No. 2 but much like No. 1 from the alluvial sand quoted in the table.

Mineral analyses of water in Richland County.

(Analyses in parts per million)

	Surface deposits.	
	1.	2.
Depth of well.....feet..	20	30
Silica (SiO_2)..... / Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$).....	4.1	1.2
Calcium (Ca).....	48.0	27.7
Magnesium (Mg).....	19.2	13.6
Sodium and potassium (Na+K).....	28.2	26.4
Carbonate radicle (CO_3).....	119.7	88.5
Sulphate radicle (SO_4).....	13.5	19.0
Chlorine (Cl).....	30.3	14.4
Total dissolved solids.....	261.	188.

1. Railroad well at Richland Center, Analyst, Chemist, C. M. & St. P. Ry. Co., Dec. 30, 1891.
2. Railroad well at Lone Rock, Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 3, 1891.

ROCK COUNTY

Rock county, located on the southern boundary of the state, has an area of 706 square miles and a population of 55,538. About 95.9 per cent of the county is in farms of which 81.8 per cent is under cultivation.

SURFACE FORMATION

The surface of Rock county consists of broad level valley bottoms and undulating uplands. The broad belt of terminal moraine, the Kettle moraine, trends nearly east and west across the northern part of the county. A broad nearly level tract extends south of Janesville along the Rock river, and eastward along the Kettle moraine. With the exception of the terminal moraine, the land in the western part of the county reaches higher elevations than that of the eastern part. The altitude of the Rock river above the dame at Beloit is 741 feet, above the Ford dam at Janesville 769, and at Lake Koshkonong 779 feet. The broad valley bottom of the Rock river at Beloit and Janesville has an altitude of about 800 feet, about the same as Lake Koshkonong and the river at Fort Atkinson in Jefferson county. The river itself, however, is entrenched more deeply in the valley bottom plain below Janesville than at Lake Koshkonong.

North of Janesville where the river cuts through the moraine the valley is relatively narrow and the old valley is occupied by drift hills. The uplands in the northwestern part of the county in the town of Magnolia reach an altitude of 1,080 feet. The uplands in the southeastern part do not reach 1,000 feet while those of the northeastern part reach up to 1,050 feet. The difference in elevation between valley bottoms and adjacent uplands in the county is about 300 feet.

GEOLOGICAL FORMATIONS

The geological formations, showing rock outcrops, are the St. Peter sandstone and the Galena-Platteville (Trenton) limestone. The northeastern part of the county is covered with a thick mantle of glacial drift. The valleys are filled with a thick deposit of alluvial gravel and sand. The geological structure is illustrated in Fig. 64.

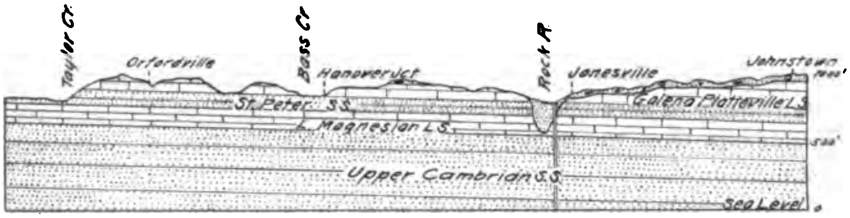

Fig. 64.—Geologic section, east-west, across central Rock County.

The surface deposits in the pre-glacial Rock river valley, have a thickness of 350 feet at Janesville. The usual thickness of the Upper Cambrian (Potsdam) sandstone is probably about 800 feet, and of the St. Peter sandstone and Lower Magnesian limestone combined between 200 and 250 feet.

The approximate range in thickness of the formations in the county may be summarized as follows:

Approximate range in thickness of formations in Rock County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena-Platteville (Trenton) limestone	0 to 200
St. Peter and Lower Magnesian	0 to 250
Upper Cambrian (Potsdam) sandstone	600 to 800
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizons are the "Potsdam" sandstone, the St. Peter sandstone, and the superficial deposits of glacial drift and alluvial deposits. The limestone formations also have abundant crevices and openings which are filled with ground water below the general ground water level.

FLOWING WELLS

Flowing wells occur on low ground along Rock river and tributaries in both the surface formation and the underlying Upper Cambrian (Potsdam) sandstone. At Beloit, the source of the flows is in the drift below red clay, the city wells being 90 feet deep and having a normal head of 5 or 10 feet above the surface. At Janesville and Edgerton, flows are obtained from the Upper Cambrian sandstone. The city wells in Janesville, over 1,000 feet deep, yield strong flows under a 24 to 28-foot head, at altitudes of the curb of 774 feet. The old city well in Edgerton, 495 feet deep, when properly packed, has a normal head of 12 feet, altitude of curb 821 feet. Other flowing wells in Edgerton, varying in depth from 198 to 572 feet, flow from 2 to 17 feet above the surface.

Flowing wells can probably be obtained in Rock county at elevations not exceeding 25 or 30 feet above Rock river, the head rising to the north with the general slope of the strata, and also up the side valleys. The height to which the water will rise is influenced by local conditions in the surface deposits as well as leakage from the underground sources in the old pre-glacial valleys.

In the valley of the Sugar river in the southwestern part of the county, flowing wells are obtained under conditions similar to those in the Rock river valley, as indicated by the flowing wells at Brodhead.

SPRINGS

Springs occur on low ground in many parts of the county. A common zone for the issuance of springs is the shaly strata at the junction of the St. Peter sandstone and the overlying Platteville limestone, in the valleys of the western part of the county. There are numerous springs in the towns of Spring Valley and Avon. Springs are also quite common in the northern part of the county at the foot of the drift hills of the Kettle Moraine. Some well known mineral springs occur at Beloit.

WATER SUPPLIES FOR CITIES AND VILLAGES

Janesville. The population of Janesville is 13,894. The city water supply is mainly obtained from two flowing artesian wells, 1,087 and 1,031 feet deep. A part of the supply is obtained from a large open well 25 feet deep. The artesian wells flow into a large reservoir, the capacity of which is 796,000 gallons. A growth of green algae sometimes develops along the sides and bottoms of the reservoir. The system is connected with an intake extending into the Rock river, which is connected with a sand filter. The average daily pumpage is 1,164,000 gallons. About 80 per cent of the houses are connected with the water system.

The first artesian well, 1,087 feet deep, has a diameter of 10 inches as far as cased, 254 feet, below which the diameter is 8 inches. Elevation of curb is 774. At depth of 300 feet this well began to flow, and the yield increased rapidly after a depth of 800 feet was reached. This well when completed flowed 587 gallons per minute under a 28-foot head. The second well, 1,031 feet deep, 10 inches in diameter, drilled in 1898, is 800 feet from the first. This well flowed about 500,000 gallons per day under a 25 foot head. The pumpage in 1898 was about 650,000 gallons per day. During the night from 3 to 4 hundred thousand gallons flowed into the river from the two wells.

The deep well at the Fair Grounds, drilled in 1874, is 1,033 feet deep, 350 feet in drift, and 683 feet in the Potsdam sandstone. There are four other wells in the city ranging from 400 to 500 feet in depth. None of these wells are flowing wells, the surface of the ground at the wells being too high. Many shallow wells in the city vary in depth from 20 to 100 feet in the drift.

Beloit. The population of Beloit is 15,125. The water supply is obtained from a system of driven wells which flow into a large reservoir 30 feet in diameter and 40 feet deep, having a capacity of 423,000 gallons. The water is pumped from the reservoir, the average daily pumpage being nearly two million gallons. An intake extends into the Rock river, connected with a sand filter. The sewage from only a small part of the city is treated before being drained into the Rock river. About 70 per cent of the houses are connected with the water supply and about 30 per cent, with the sewage system.

The well supply comes from the drift below the red clay. Forty-five well points varying from 4 to 6 inches in diameter and 16 feet long have been driven down about 90 feet. Most of these wells are on the east side of the river and the water rises in the pipes in places as much

as 8 feet above the surface. The depth of the drift is very irregular, but it seems very probable that a considerable portion of this water is fed directly to the gravel and porous beds of the drift by the underlying St. Peter sandstone in which the pre-glacial valleys were eroded. For flowing wells in the Rock river basin, see pages 75 and 96.

Edgerton. The population is 2,513. The city has a municipal waterworks, the average daily pumpage being 243,000 gallons. About 80 per cent of the houses are connected with the supply. The city sewage is emptied, without treatment, into the Rock river.

The source of the city water supply is one 10-inch artesian well, 1,000 feet deep.

Log of Edgerton City Well.

Formation.	Thickness.
	Feet.
Drift	120
Limestone (Lower Magnesian	160
Sandstone and shale (Potsdam)	720
Total depth	1000

This well flows 200 gallons per minute at the surface, and yields, when pumped, 450 and 550 gallons per minute at 12 and 20 feet below the surface respectively. In drilling this deep city well the head at the old city well dropped 14 feet. The old city well is 495 feet deep; 140 feet in drift and 355 feet in rock. In order to get a flow at the latter well it was necessary to pack the well at a depth of 480 feet; then the water rose 12 feet above the surface.

The Chicago, Milwaukee & St. Paul Railway well drilled in 1903 by W. L. Thorn is 508 feet deep, 108 feet in drift, and 400 feet in sandstone. The elevation of the curb is 825 feet and the water stands 14 feet below the surface.

Evansville. The population is 2,061. The city water supply is obtained from two wells, 8 feet in diameter, and 27 feet deep. The wells are 30 feet apart, sunk in gravel beds. The average daily pumpage is 53,000 gallons. About 50 per cent of the houses are connected with the water supply. The city has no sewage system.

Clinton. This village, population 897, has a public water supply obtained from a well 6 inches in diameter and 900 feet deep, the source

being the St. Peter sandstone. The average daily pumpage is 30,000 gallons. About 75 per cent of the houses are connected with the water supply.

Milton Junction. Milton Junction has a public water supply obtained from a well 220 feet deep. The average daily pumpage is about 4,000 gallons, about 35 houses being connected with the system. No sewage system is installed.

QUALITY OF THE WATER

The mineral analyses of water supplies from various parts of the county are shown in the following table. All the waters, except one, are of moderate mineral content, and all would be classed as hard waters rather than very hard waters. All are carbonate waters, in which calcium and magnesium greatly predominate over sodium. The railroad well at Edgerton, No. 6 high in mineral content, contains much more than the average amount of chlorine, indicating a considerable amount of pollution from contaminated sources.

The Rock river water at Rockford, Illinois, is included in the table, since the river water at Rockford is likely to be much like that at Beloit and Janesville. The river water, it will be noted, is almost as hard as the well waters. The well waters from the surface deposits are somewhat higher in mineral content than that from the deep wells in the underlying Potsdam sandstone. Most of the waters analyzed appear, however, to be either from sandy surface deposits or from the underlying sandstone, and hence, are very probably not quite so hard as those water supplies obtained from either the Lower Magnesian or the Galena-Platteville (Trenton) limestone formations.

In the city water supplies of Janesville and Beloit there is an average of about 2.25 lbs. of incrusting solids in 1,000 gallons. In the city water supply of Evansville, No. 4, there are 2.80 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Rock County.

(Analyses in parts per million)

	Creek.	River.	Spring.	Surface deposits.		
	1.	2.	3.	4.	5.	6.
Depth of well ... feet	Undt...	....	....	29.	30.	28.
Silica (SiO_2) ...		15.	13.0	17.9	17.4	2.2
Aluminium and iron oxides ($Al_2O_3 + Fe_2O_3$) ...	....	....	....	8.9	2.0	....
Aluminium oxide (Al_2O_3) ...	....	....	1.0	....	....	....
Iron (Fe) ...	....	0.44	0.2	....	....	....
Calcium (Ca) ...	52.4	45.	61.5	68.2	38.0	112.4
Magnesium (Mg) ...	33.3	25.	34.8	36.4	43.9	67.6
Sodium (Na) ...	13.2	1C.	3.0	2.1	8.8	25.8
Potassium (K) ...			2.3			
Carbonate radicle (CO_3) ...	162.0	123.9	179.	173.4	140.8	303.3
Sulphate radicle (SO_4) ...	15.4	22.	4.6	30.2	48.4	61.7
Chlorine (Cl) ...	7.3	4.6	3.5	7.6	6.9	32.7
Iodine ...	....	....	0.1	....	....	....
Suspended matter ...	....	92.	....	....	....	....
Nitrate (NO_3) ...	....	4.1	....	....	....	....
Total dissolved solids ...	283.	250.	303.	345.	306.	606.

	Surface deposits—Continued.					
	7.	8.	9.	10.	11.	12.
Depth of well ... feet	48.	48.	60.	72.	25.	25.
Silica (SiO_2) ...	5.3	Undt...	1.3	Undt...	Undt...	Undt...
Aluminium and iron oxides ($Al_2O_3 + Fe_2O_3$) ...	....	....	....	....	....	....
Calcium (Ca) ...	79.5	98.6	65.1	99.6	51.0	56.0
Magnesium (Mg) ...	38.0	49.1	30.7	34.4	26.5	27.8
Sodium and potassium (Na + K) ...	14.6	48.9	10.9	2.8	3.6	6.5
Carbonate radicle (CO_3) ...	194.3	163.3	173.7	165.9	122.3	142.0
Sulphate radicle (SO_4) ...	41.2	269.5	16.1	42.4	19.2	19.6
Chlorine (Cl) ...	14.6	Undt...	4.9	Undt...	6.2	7.3
Nitrate radicle (NO_3) ...	....	....	....	....	18.2	....
Total dissolved solids ...	387.	628.	307.	315.	242.	259.

1. Turtle Creek, Beloit, Analyst, G. N. Prentiss, June 22, 1912.
2. Rock River at Rockford, Ill., Average Mineralization, Analyst, R. B. Dole, U. S. Geol. Sur. W. S. P., No. 236, p. 118, 1909.
3. Iodo-Magnesium Spring, Beloit, Analyst, C. F. Chandler, Wis. Geol. Sur., Vol. 2, p. 8, 1877.
4. City Wells, Evansville, Analyst, G. M. Davidson, Jan. 1902.
5. Well of C. & N. W. Ry. Co., Koshkonong, Analyst, G. M. Davidson, June 23, 1896.
6. Well of C. M. & St. P. Ry. Co., Edgerton, Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 20, 1889.
7. Well of C. M. & St. P. Ry. Co., Janesville, Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 5, 1891.
8. Well of C. M. & St. P. Ry. Co., Janesville, Analyst, Chemist, C. M. & St. P. Ry. Co., June 8, 1900.
9. Well of C. M. & St. P. Ry. Co., Milton, Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 28, 1889.
10. Well of C. M. & St. P. Ry. Co., Milton, Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 6, 1902.
11. Well of H. Miller, Beloit, Analyst, G. N. Pentiss, July 10, 1912.
12. Well at Fair Ground, Beloit, Analyst, G. N. Pentiss, July 2, 1912.

Mineral analyses of water in Rock County—Continued.

	Surface deposits—Continued.				Upper Cambrian sandstone.	
	13.	14.	15.	16.	17.	18.
Depth of well .... feet	30.	100.	100.	100.	189.	500.
Silica (SiO_2)	Undt...	5.9	1.7	3.1	Undt...	... .
Aluminium and iron oxides ($Al_2O_3 + Fe_2O_3$)	....	....	....	8.	....	....
Calcium (Ca)	45.3	61.0	64.7	59.6	88.2	70.7
Magnesium (Mg)	23.0	25.6	28.9	31.6	48.3	....
Sodium and potassium (Na + K)	5.1	5.2	6.9	18.2	11.7	15.5
Carbonate radicle (CO_3)	105.4	153.8	162.4	167.5	219.4	100.3
Sulphate radicle (SO_4)	20.1	8.0	18.4	23.6	74.6	9.2
Chlorine (Cl)	6.2	2.1	4.4	10.5	Undt...	24.0
Nitrate radicle (NO^8)	14.4	....	....	....	....	....
Total dissolved solids	219.	261.	287.	322.	442.	220.

	Upper Cambrian (Potsdam) sandstone.							
	19.	20.	21.	22.	23.	24.	25.	26.
Depth of well .... feet	650.	1,160. 1,087.	1,100.	1,300.	1,160.	1,087.	1,031.	1,452.
Silica (SiO_2)	Undt.	9.1	9.4	7.0	2.2	8.4	Undt.	8.4
Aluminum and iron oxides ($Al_2O_3 + Fe_2O_3$)	....	6.8	1.5	2.0	3.1	....	....	....
Iron (Fe)	......	0.4	....	....	....	....	....	....
Calcium (Ca)	48.7	50.4	64.1	54.2	53.7	50.3	63.5	50.3
Magnesium (Mg)	32.4	35.9	37.9	38.5	39.	34.3	38.4	34.3
Sodium (Na) / Potassium (K)	10.4	5.4 / 0.8	5.5	3.7	17.2	11.5	5.3	11.5
Carbonate radicle (CO_3)	152.9	165.6	180.4	175.[illegible]	184.5	168.3	187.4	163.3
Sulphate radicle (SO_4)	10.7	5.6	14.4	2.[illegible]	13.6	8.4	14.0	8.4
Chlorine (Cl)	7.0	4.9	8.5	3.[illegible]	7.0	6.7	Undt.	6.7
Total dissolved solids	262.1	285.	321.	287.	320.	285.	309.6	285.

13. Well of J. C. Cressinou, Beloit, Analyst, G. N. Prentiss, July 10, 1912.
14. Well of City Water Supply, Beloit, Analyst, Chemist, C. M. & St. P. Ry. Co., April 9, 1891.
15. Well of City Water Supply, Beloit, Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 9, 1895.
16. City Water Supply, Beloit, from main ,Analyst, Dearborn Drug & Chem. Co., Oct. 16, 1907
17. Well of C. M. & St. P. Ry. Co., Edgerton, Analyst, G.N. Prentiss, February 8, 1902.
18. Well of T. F. Knipp, Janesville, Analyst, A. Fisher.
19. Well at Crooke's Brewery, Janesville, Analyst, G. N. Prentiss, Jan. 12, 1906.
20. Well of City water supply, Janesville, Analyst, E. G. Smith.
21. Two wells of C. & N. W. Ry. Co., Round House, Janesville, Analyst, G. M. Davidson, June 23, 1896.
22. Artesian well of City Water Co., Janesville, Analyst, G. M. Davidson, Feb., 1892.
23. Artesian well of City Water Co., Janesville, Analyst, Dearborn Drug & Chem. Co., Oct. 5, 1907.
24. City well, Janesville, Analyst, Chemist, C. M. & St. P. Ry. Co., Dec. 2, 1891.
25. City well, Janesville, Analyst, Chemist, C. M. & St. P. Ry. Co., June 8, 1900.
26. Well of C. M. & St. P. Ry. Co., Janesville, Analyst, G. N. Prentiss, May 14, 1906.

Rusk County

Rusk county, located in the north central part of the state, has an area of 916 square miles, and a population of 11,160. About 19.2 per cent of the county is in farms, of which 22.8 per cent is under cultivation.

SURFACE FEATURES

The surface is mainly a broad undulating plain, with the exception off the northwestern part, which is characterized by prominent rock ridges. A belt of terminal moraine extends northward across the western part. The county is traversed by the Chippewa and Flambeau rivers, flowing south through the central portion. The altitude of most of the county lies between 1,100 feet in the southern part and 1,300 feet in the northern part. The high ridges in the northwestern part probably reach up to elevations of 1,500 and 1,600 feet.

GEOLOGICAL FORMATIONS

The principal formations are the deposits of glacial drift, sand and gravel. The underlying rock consists of granitic formations, mainly outcropping along the river, and the high ridges of quartzite in the northwestern part of the county. The surface formation is of variable thickness, probably reaching a maximum of 200 or 250 feet in places.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizon is the surface formation of glacial sand and gravel. The wells are generally quite shallow, usually from 20 to 40 feet over the entire county.

At Tony wells are from 10 to 25 feet deep in the drift, the water level standing from 10 to 20 feet below the surface. The railroad well in Glen Flora is 120 feet deep, wholly in drift. At Glen Flora the wells are generally from 20 to 40 feet deep. In Ingram no deeper wells than 24 feet were found, and these wholly in drift. In Hawkins most of the wells were less than 21 feet deep, wholly in drift.

WATER SUPPLIES FOR CITIES AND VILLAGES

Ladysmith. Ladysmith, the county seat, is the principal city, with a population of 2,352. It is located upon the Flambeau river, on the site of a water power. The elevation at the top of the dam is 1,115 feet above sea level. The city is built upon land rising up to 60 to 80 feet above the level of the Flambeau river. The formation is a sandy, and a clayey, gravelly drift. The city has a public water supply and sewage system. The city supply is obtained from the Flambeau river and is not very satisfactory. The daily consumption of water is about 100,000 gallons. About 25 per cent of the houses connect with the city supply. The private wells in the city vary in depth between 25 and 80 feet. The sewage, without treatment, is emptied into the Flambeau river.

Bruce. Bruce has a population of 565, elevation, 1,098 feet. It is located on the west bank of the Chippewa river, on a sandy gravelly plain, with sandy loam soil. Private wells are generally from 15 to 30 feet deep. In 1908 a waterworks system was installed. The supply is derived from two 6-inch wells, 43 feet deep, in sand and gravel. The water level stands 16 feet below the surface. The daily capacity of the wells is 60,000 gallons. The wells can be emptied in about three hours.

QUALITY OF THE WATER

No analyses of the water of the county are at hand, but judging from the character of the geological formations, the supplies are very likely to be mainly soft water of low mineral content throughout the entire county.

St. Croix County

St. Croix county, located in the northwestern part of the state, has an area of 711 square miles, and a population of 25,910. About 88.8 per cent of the county is laid out in farms, of which 71 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is mainly an undulating upland plain on the Lower Magnesian limestone formation. In the western part are a

few mounds of the Platteville (Trenton) limestone extending above this general plain. Over a considerable part of the southern half of the county the surface drainage is carried off by temporary streams. The valleys are deeply incised only within a few miles of the St. Croix river, which lies in a deep and narrow trench 200 to 300 feet below the upland immediately adjacent, and 400 to 500 feet below, the upland in the eastern part of the county. The altitudes generally range from 700 feet along the St. Croix river bottom to 1,000 and 1,200 feet on the upland plain.

GEOLOGICAL FORMATIONS

The geological formations are similar to those in Pierce county, and consist, from the base upward, of the Upper Cambrian or St. Croixan (Potsdam) sandstone, Lower Magnesian limestone, St. Peter sandstone and the Platteville (Trenton) limestone. Glacial drift is abundant over most parts of the county. A belt of thick drift hills, terminal moraine, extends northeast across the northwest part of the county. The geological structure is illustrated in figure 65.

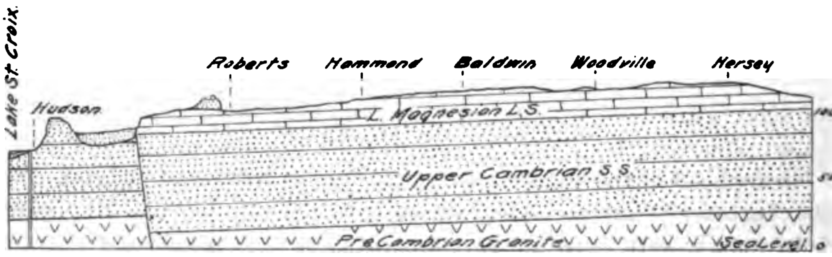

Fig. 65.—Geologic section, east-west, across southern St. Croix County.

The thickness of the surface formation of glacial drift is variable on account of the irregularities in the rock surface upon which it was deposited, as well as the irregularity in the deposition of the drift in the form of ridges, depressions and level tracts. There are many wells in the county which have penetrated 200 feet of drift, but the usual thickness is 25 to 100 feet. At the railroad shop well in Hudson, about 104 feet of surface deposit was penetrated before striking the rock formation. This well is situated on the bottoms of the St. Croix and indicates that the old pre-glacial channel is at least 100 feet below the present level of the St. Croix, a condition closely corresponding to that of the old channel of the Mississippi at St. Paul[1]. The thickness of the

[1] U. S. Geol. Survey, W. S. P. 256, p. 302.

rock formations is variable on account of the extensive erosion of the strata. The complete thickness of any formation is preserved only where protected by the overlying formation, as indicated in the cross section. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in St. Croix County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Platteville (Trenton) limestone	0 to 150
St. Peter and Lower Magnesian	0 to 300
Upper Cambrian (Potsdam) sandstone	300 to 800
The Pre-Cambrian formation	....

PRINCIPAL WATER-BEARING HORIZONS

The water supplies over the upland plain are obtained mainly from the Lower Magnesian limestone horizon and from the overlying glacial drift. In the deeper wells, those from 150 to 250 feet, deep, the underlying Upper Cambrian (Potsdam) sandstone is drawn upon. In the northern part of the county, where the Upper Cambrian or St. Croixan (Potsdam) sandstone is usually near the surface, this formation is the common source of supply. The cities of Hudson and Glenwood, located in the valleys, obtain their supply from the Upper Cambrian sandstone, while New Richmond, located on the upland plain, draws its supply from sandstone beds within the Lower Magnesian horizon.

FLOWING WELLS

Artesian flows in surface formations supply the trout springs, located in the valley of the Willow river, near Hudson. The well pipes extend to a depth of 12 to 18 feet, the water generally rising a foot or two above the general level of the ponds. The wells are driven through a clayey stratum, into the underlying sand and gravel beds, where the water is under pressure. The alluvial formation has developed an artesian slope the head rapidly decreasing in conformity with the slope down the valley.

The absence of flowing wells on low ground, along the St. Croix river, at Hudson, in view of the fact that flows are readily obtained along the Mississippi river at St. Paul, 18 miles to the west, with head 40 to 60 feet above the level of the St. Croix river at Hudson, and at River

Falls, only 12 miles to the southwest, with head nearly 200 feet above the level of the river at Hudson, may be worthy of a brief discussion in connection with a description of the water supplies of this locality.

The reason for the absence of flowing wells in the rock formation at Hudson is apparently due to unfavorable underground conditions, to dislocation in the rock strata, as Hudson is located on an uplifted zone or segment of the strata. This uplifted segment has an approximate width of about 4 miles at Hudson and extends northeast and southwest across the northwest part of St. Croix county. The eastern boundary of this uplifted segment is fairly well defined, being marked by a zone of faulting or sharp folding extending through the locality of the Ilwaco springs on the St. Croix, to Willow river Falls, at Burkhardt, and to Little Falls on the Apple river, in southern Polk county, and apparenly continuing for an undetermined distance farther northeast. South of the locality of the Ilwaco Springs the boundary of this dislocated zone, which is marked either by a series of short faults or by a sharp monoclinal fold, has been recognized at Point Douglas, near Hastings, as described by N. H. Winchell[1] and also by Owen[2] at a much earlier date. Within this uplifted segment the Upper Cambrian sandstone strata stand 200 to 300 feet above the equivalent strata to the east, at Chapman and River Falls, and 200 to 400 feet above the same strata to the west, at Stillwater and St. Paul. The soft sandstone in this uplifted belt, being of softer rock than the hard limestone lying to the east and to the west, has led to the development of a deep valley at Hudson within the sandstone belt, which valley, as already referred to, is at least 100 feet, and possibly much deeper below the present surface of the St. Croix river. The discontinuity of the rock strata within this dislocation zone, with that outside of it, has been the principal factor in destroying the conditions for development of artesian flows from the sandstone strata at Hudson, and a minor factor tending to destroy favorable artesian conditions may also have been the subsequent location of a deeply eroded valley within the same area.

Conditions appear to be favorable for the development of flowing wells along the St. Croix river, south of the fault at Ilwaco springs.

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[1]Geology of Minnesota, Vol. 2, page 384.

[2]Owen's Geological Survey of Wisconsin, Iowa and Minnesota, p. 46, Geol. Sect. No. 5.

SPRINGS

Springs are relatively rare in the interior of the county on the summit of the upland plain, but are quite common near the outer border of the county, along the streams whose valleys head in the upland plain. The springs in fact, are usually the starting point of the permanent streams that occupy these valleys. Springs are common in the eastern part of the county, along the streams flowing eastward to the Red Cedar river, such as the Bolan Creek, Sandy Creek, Tiffiany Creek, Beaver Creek, and Wilson Creek.

In the southern part of the county springs are common on the valley bottoms and along the tributary valleys of the Eau Galle, Rush and Kinnikinnic rivers. In many instances the springs determine the location of farm houses, and furnish an excellent supply of water for domestic use.

Springs are also quite common along the St. Croix valley, wherever the rock formation is exposed, as illustrated at Hudson, where conditions are favorable for the issuance of springs at the contact of the shale and sandstone beds. The Ilwaco Springs on the St. Croix issue from the base of the Lower Magnesian limestone and are utilized as a summer resort. There are a few springs along the Willow river, and also some especially large springs along the Apple river. An important spring flows into the Apple river, near Star Prairie, at a place locally known as New Saratoga Springs.

WATER SUPPLIES FOR CITIES AND VILLAGES

Hudson. Hudson, situated on Lake St. Croix, an expansion of St. Croix river, has a population of 2,810. The city is located on the side of the valley, on outcropping sandstone, only a thin coating of alluvial formation being generally present. The public water supply of Hudson is obtained from two 6-inch artesian wells, stated to be 375 and 658 feet deep, and located about 75 feet apart, near the shore of Lake St. Croix. The two wells are connected with a pipe 7 feet below the surface and this pipe is connected with suction pipes at the pumps. The water in the two wells drops 23 feet when pumping at the rate of 450 gallons per minute, but the normal head returns shortly after pumping stops. The supply is somewhat short, but may be increased by pumping from a greater depth. The average daily pumpage is 598,000 gallons. Nearly all the houses are connected with the city supply. Only a limited sewage system is installed, which empties into the St. Croix river. A third well was recently drilled for the city supply.

No record of the formations passed through in drilling the city wells has been kept, but from description the sandstone formation was encountered near the surface, and a hard rock formation was struck at depth of about 375 feet. The first well was drilled 658 feet, about 300 feet into this hard rock without increase of water; hence, the second well was stopped at 375 feet. The hard formation is evidently an older formation than the Upper Cambrian sandstone, probably the same as that struck below the Upper Cambrian (St. Croixan) sandstone at Stillwater, described[1] as the "red clastic series."

The well of the C., St. P., M. & O. Railway at the railroad shop yards, 12 inches in diameter, 450 feet deep, capacity 300 gallons per minute, has the following log:

Log of Well of C. St. P., M. & O. Ry. at shop yards, at Hudson.

Formation.	Thickness.
	Feet.
Surface formation—	
Sand	5
Coarse gravel	3
Sand	21
Clay	7
Sand and gravel	54
Clay	14
Upper Cambrian (Potsdam) sandstone formation—	
Sandstone with thin strata of shale	16
Shale	90
Sandstone	240
Total depth	450

The curb of this well is but a few feet above the St. Croix river. The thickness of the surface formation is 104 feet and indicates that the bottom of the old channel is at least 100 feet below the present river level.

New Richmond. New Richmond, located on the Willow river, has a population of 1,988. The public water supply is obtained from 6 wells from 57 to 110 feet deep. The first 20 or 30 feet is sandstone, below which is limestone. The water rises to 12 or 14 feet of the surface. The average daily pumpage is 125,000 gallons. About 30 or 40 per cent of the houses are connected with the water supply. No city sewage system is installed. Many of the private wells in the city are shallow, from 10 to 30 feet deep, in drift and rock. Wells in the city are from

[1]U. S. Geol. Survey, W. S. P. No. 256, p. 366.

20 to 60 feet deep and get their supply from the limestone. Quite generally, on the prairie about New Richmond, the wells are from 10 to 30 feet in the drift and gravel overlying the Lower Magnesian limestone.

Glenwood. Glenwood, a city of 954 population, is situated on the Tiffany Creek. The city water supply is from a well 280 feet deep, with about 50 feet surface gravel, and 230 feet of sandstone. About 25 per cent of the families use the city water. The average daily pumpage is 62,000 gallons. No sewage system is installed. The private wells in the city are generally from 20 to 60 feet deep, depending upon elevation above the creek. Some of the wells on the uplands, northwest of Glenwood, are 200 feet deep.

Baldwin. This village, population 594, has a city water supply obtained from two 6 to 8-inch wells, 117 and 132 feet deep. The estimated capacity is 25,000 gallons per day; the daily pumpage is 20,000 gallons. About 75 per cent of the houses connect with the city water supply. Private wells are generally about 100 feet deep.

Hammond. This village, population 408, has a city water supply used mainly for fire protection.

Burkhardt. In Burkhardt the wells are from 75 to 110 feet deep in drift and limestone.

QUALITY OF THE WATER

Mineral analyses of water of the spring at Saratoga Springs, and of the railroad wells and city wells at Hudson, are shown in the following table: The water of Saratoga Springs, analysis of which was made many years ago, 1870–75, is apparently very high in iron and should be classed as a chalybeate water. The analyses of waters from the railroad and city wells in Hudson are essentially identical. These are hard calcium carbonate waters of moderate mineral content. The amount of incrusting solids in the city water calculated from the above mineral analyses, No. 4, is 1.61 pounds in 1,000 gallons. The waters obtained from wells in the limestone are very probably only slightly higher in mineral content than those of the above table, from wells in the sandstone.

Mineral analyses of water in St. Croix County.

(Analyses in parts per million)

	Spring.	Upper Cambrian "Potsdam" sandstone.			
	1.	2.	3.	4.	5.
Depth of well.....feet.	....	300	450	375	375
Silica (SiO_2)	17.6	14.27	9.42	11.81	12.67
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	1.88	7.36	1.88	2.23
Iron (Fe)	4.0	....	....	....	....
Calcium (Ca)	16.9	45 96	44.12	43.97	42.82
Magnesium (Mg)	8.7	20.35	16.01	15.85	20.04
Sodium and potassium (Na+K)	5.1	11.52	12 05	8.56	4.90
Carbonate radicle (CO_3)	58.	126 89	126.35	102.80	109.74
Sulphate radicle (SO_4)	0 9	12.38	10 65	12.11	5.56
Chlorine (Cl)	1.4	6.75	7.46	6 85	7 68
Total solids	113.	240.	233	204.	206.

1. New Saratoga Springs, Sec. 6, T. 31, R. 17 W, Analyst G. Bode, Sept. 9, 1875, Geol. of Wis., Vol. IV, p. 145.
2. Well of C. St. P. M. & O. railroad shops, Hudson, sample taken at depth of 300 feet, Analyst, G. M. Davidson, July 21, 1910.
3. Well of C. St. P. M. & O. railroad shops, Hudson, sample taken at depth of 450 feet, Analyst, G. M. Davidson, July 2, 1910.
4. Wells of city water supply, Hudson, Analyst, G. M. Davidson, Mar. 18, 1909.
5. Wells of city water supply, Hudson, Analyst, G. M. Davidson, July 9, 1909.

SAUK COUNTY

Sauk county, located in the south central part of the state, has an area of 820 square miles, and a population of 32,869. About 93.4 per cent of the county is in farms, of which 56.2 per cent is under cultivation.

SURFACE FEATURES

The most prominent topographic feature of the county is the Baraboo Bluffs[1], which attain a height east of Devils Lake of over 1,620 feet above sea level, and about 800 feet above the adjacent valley bottoms of the Baraboo and Wisconsin rivers.

The Baraboo valley extends east and west through the county, a large portion lying between the north and south ranges of the Baraboo Bluffs. The Wisconsin river has a broad flat valley along the southern boundary of the county, and on the northeastern boundary. The

[1]For details of the geology of the Baraboo region, see Bulletins V and XIII, Wis. Geol. & Nat. Hist. Survey.

western part of the county is a broad tableland deeply dissected by valleys. The uplands generally reach an altitude of 1,100 to 1,300 feet, parts of the Baraboo quartzite bluffs rising still higher. The bottom lands along the Wisconsin river are usually about 800 feet above sea level and along the Baraboo river from 800 to over 900 feet.

GEOLOGICAL FORMATIONS

The geological formations outcropping in this county are the Baraboo quartzite, the Upper Cambrian (Potsdam) sandstone, and the Lower Magnesian limestone. The quartzite, of Pre-Cambrian age

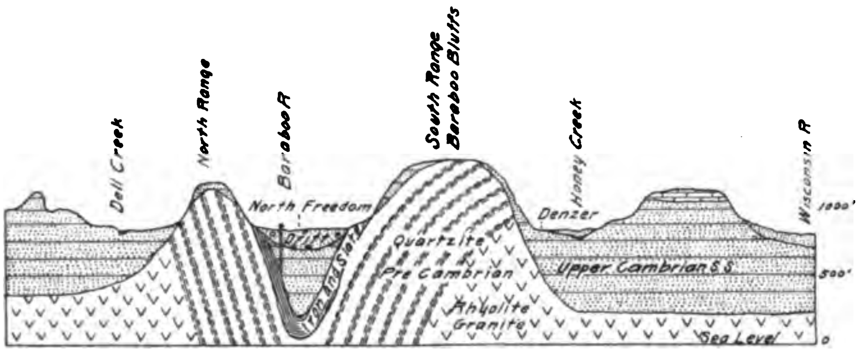

Fig. 66.—Geologic section, north–south, across central Sauk County.

forms the prominent Baraboo Bluffs, two parallel ridges extending east and west across the central part of the county. The Upper Cambrian sandstone flanks these ridges and forms the main outcrop in the northern part of the county and in the valley bottoms in the southern and western part. A few occurrences of the Mendota dolomite occur near Baraboo. The Lower Magnesian limestone forms the main upland area of the western part of the county. Glacial drift is an abundant formation in the eastern part of the county. Alluvial gravel and sand fills the principal valleys, such as the Baraboo and Wisconsin rivers, to a depth of 50 to over 200 feet. The general geologic structure is illustrated in Fig. 66.

The thickness of the surface formations is quite variable, due to uneven surface upon which they are deposited, and to the unequal amounts of glacial drift in the terminal moraine that extends north and south across the county. The thickness of the rock formations of Upper Cambrian (Potsdam) sandstone and Lower Magnesian limestone also varies greatly, due to the extensive erosion of these formations since they were deposited, as well as to the very uneven surface of the

Pre-Cambrian quartzite bluffs, upon which they were deposited. The maximum thickness of the Upper Cambrian (Potsdam) formation is probably developed nowhere immediately, adjacent to, or within the quartzite ranges, but may attain a complete section a few miles outside the ranges. There is very thick sandstone in the vicinity of the quartzite ranges in Pine Bluff near the Lower Narrows. The approximate range in thickness of the formations may be summarized as follows:

Approximate range in thickness of formations in Sauk County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Lower Magnesian limestone	0 to 200
Upper Cambrian (Potsdam) sandstone	0 to 900
Pre-Cambrian quartzite and slates in the Baraboo Bluffs over 5000 or 6000 feet thick.	

PRINCIPAL WATER-BEARING HORIZONS

Water is obtained from all the geological formations of the district, but the most important water-bearing horizons are the Upper Cambrian (Potsdam) sandstone and the alluvial and glacial deposits. Only a small supply can be obtained from the quartzite of the Baraboo bluffs, but where an appreciable thickness of sandstone or drift overlies the quartzite, enough for domestic purposes on the farms is readily available. Some of the wells in the quartzite on the Baraboo Bluffs reach a depth of 500 to 600 feet. On the lower uplands of sandstone, outside of the quartzite bluffs, sufficient water is obtained at the prevailing groundwater level of the region.

FLOWING WELLS

On low ground along the Baraboo river artesian flows are obtained. On the higher slopes of the uplands the water in many places in deep wells is under pressure, but does not rise to the surface.

Along the Baraboo valley east of Ablemans, flows have been obtained from the alluvial sand and the underlying sandstone. In the vicinity of Reedsburg and Wonewoc flows have been obtained from sand and gravel beneath beds of clay. The flows are confined for the most part to the lowland along the Baraboo river as far east as the Lower

Narrows. In La Valle, the non-flowing wells are generally from 15 to 30 feet deep in sand, or sandstone and the flowing wells much deeper.

Ablemans. At Ablemans a well 69 feet deep flows about 7 gallons per minute. The water is obtained from the sandstone. Common wells in Ablemans vary from 25 to 60 feet in sand and sandstone. There are several flowing wells in the village, the artesian heads reaching 15 to 20 feet above the river level.

North Freedom. There are many flowing wells within the district prospected for iron ore in the vicinity of North Freedom[1]. In fact, most of the drill holes sunk on low ground in prospecting for iron ore give rise to flows from the surface sand and the sandstone. Common wells in North Freedom generally range between 25 and 50 feet in sand.

There are also some flowing wells in the southwest part of Sec. 17, T. 11, R. 5, and at various other places in the Baraboo valley. For additional data concerning flowing wells in the Baraboo Valley see pages 71–3.

WATER SUPPLIES FOR CITIES AND VILLAGES

Baraboo. This city, having a population of 6,324, located on the Baraboo river, has a water supply and sewage system. The present water supply is taken from two round open wells and three oblong covered springs or surface wells. The waterworks is also connected with an intake from the river, used only in case of emergency. The open wells are 15 and 23 feet deep and 15 and 20 feet in diameter respectively. The three surface wells or galleries are 100, 50 and 110 feet long, and 23, 21 and 21 feet wide, with depth of 5 feet below normal water level. The three are located on low ground, where springs appeared. This spring water comes from a sand and gravel stratum in the drift formation, and very probably is the underground flow of the creek that enters the river at this point. In times of very highest water the water supply is in danger of being flooded by polluted river water. The daily pumpage is about 700,000 gallons. The sewage is emptied, without purification into the Baraboo river at various places. Most of the private wells are from 40 to 130 feet in drift, the deeper ones having been drilled to a depth of 100 to 130 feet.

The formations passed through in the city test well, altitude of curb, about 856 feet, located about 1,320 feet west, and 200 feet south of the depot, are as follows:

[1]For further details see Bulletin XIII, Wisconsin Survey, pp. 79–89.

Log of the City Test well, Baraboo.

Formation.	Thickness.
	Feet.
Drift:	
Clay and sand	40
Bowlders	10
Sand and gravel	43
Bowlders and sand	2
Quicksand	120
Upper Cambrian (Potsdam):	
Yellow sandstone	46
Various colored sandstone	93
Coarse sandstone	70
Pre-Cambrian:	
Quartzite	4
Total	428

Upon completion the water stood 27 feet below the surface. Although the well did not flow, it furnished 125 gallons per minute, and the water was lowered only 10 feet.

Reedsburg. Reedsburg, population 2,615, has a water supply and sewage system. The water supply is from 5 wells, 6 and 8 inches in diameter, drilled to a depth of 125 to 500 feet into the sandstone. The average daily pumpage is about 300,000 gallons. About 75 per cent of the houses are connected with the water system. The sewage, without treatment, empties into the Baraboo river below the dam. Cess pools are not allowed. Most of the private wells used are from 30 to 60 feet deep in sand.

The log of one of the city water works wells is as follows:

Log of Reedsburg City Well.

Formation.	Thickness.
	Feet.
Blue clay	25
Sand with white flint gravel	35
Upper Cambrian (Potsdam) sandstone	192
Total depth	252

Water rises nearly to the level of the railroad track, about 876 feet above sea level. The natural flow is 194 gallons per minute about 15 feet above river level.

Prairie du Sac and Sauk City. The villages along the Wisconsin river, such as Prairie du Sac, Sauk City and Spring Green, are sit-

uated on sandy alluvial terraces and obtain an abundant supply of water at depth of the adjacent river level. In Prairie du Sac the wells are generally from 40 to 60 feet deep, and in Sauk from 20 to 40 feet. A public water suply was installed in Prairie du Sac in 1913, the supply being obtained from a shallow well 15 or 20 feet deep, located on the bank of the river, in the northern part of the town.

Spring Green. In Spring Green, situated about a mile from the river, the wells are generally from 15 to 30 feet deep. The deepest drilled well in the village shows a thickness of about 150 feet of alluvial sand overlying the Potsdam sandstone. The village of Spring Green has a water supply for fire protection obtained from driven wells with 8-inch Cook points.

North Freedom. North Freedom, population 647, has a water works system, the water supply being obtained from a well.

QUALITY OF THE WATER

The mineral analyses of water supplies from various parts of the county are shown in the table below. All the waters are carbonate waters of low or moderate mineral content, and all the ground waters are hard, except that from the Oliver mine, which is soft. The waters analyzed have an average content of 3.6 parts pre million of chlorine. Amounts of chlorine in excess of 6 or 7 parts per million probably indicates contamination from polluted surface waters.

The water from the Baraboo river, at Baraboo, Analyses No. 1, contains 1.26 pounds of incrusting solids in 1,000 gallons, that from the C. & N. W. R. well a Baraboo, No. 2, contains 2.26 gallons in 1,000 gallons, and that from the city water supply of Reedsburg No. 4 contains 1.82 pounds in 1,000 gallons. The water of Devils lake is very soft.

Mineral analyses of water in Sauk County.

(Analyses in parts per million)

	Lake.	River.	Surface deposits.	
	1.	2.	3.	4.
Depth of well ....feet..	....	....	25	23
Silica (SiO_2)	2.2	....		14.9
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	0.7	2.9	3.9	.5
Iron (Fe)	....	....	....	2.0
Calcium (Ca)	3.2	29.1	60.6	55.7
Magnesium (Mg)	1.1	21.5	33.4	31.3
Sodium (Na)	undet.	7.2	11.0	2.7
Potassium (K)	undet.			3.0
Carbonate radicle (CO_3)	4.1	96.9	173.3	162.2
Sulphate radicle (SO_4)	8.1	4.6	14.1	7.9
Chlorine (Cl)	8.2	7.7	6.6	1.9
Total solids	28.	170.	303.	282.

	Upper Cambrian sandstone.				Pre Cambrian iron formation.	
	5.	6.	7.	8.	9.	10.
Depth of well ....feet..	150 & 250	350	340	85.	105	380
Silica (SiO_2)	17.9	8.5	13.0	10.3	11.9	10.3
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	2.5	2.3				
Aluminium oxide (Al_2O_3)	....	....	0.1	0.5	0.1	0.1
Iron (Fe)	....	....	[illegible]	1.4	0.9	0.8
Calcium (Ca)	46.3	46.1	45.7	10.5	33.7	23.8
Magnesium (Mg)	23.5	18.6	19.6	5.6	11.2	15.9
Sodium (Na)	3.4	1.3	1.7	2.3	2.7	2.3
Potassium (K)			0.5	1.2	0.5	0.8
Carbonate radicle (CF_3)	125.4	115.3	118.4	31.9	75.9	77.2
Sulphate radicle (SO_4)	1.0	0.0	0.5	1.3	6.8	0.2
Chlorine (Cl)	5.2	3.1	2.3	2.8	3.6	2.8
Total solids	225.	195.	203.	68.	147.	[illegible]

1. Devil's Lake. Sample from Surface Analysts, E. B. Hall and C. Juday, Nov. 1908. Wis. Survey Bull. 22, p. 170.
2. Baraboo River, Baraboo, Analyst, G. M. Davidson, August 1887.
3. Well of C. & N. W. Ry. Co., Baraboo, Analyst, G. M. Davidson, June 1887.
4. City water supply, Baraboo, quoted from W. G. Kirchoffer.
5. Wells of city water supply, Reedsburg, Analyst, G. M. Davidson, Nov. 10th, 1894.
6. Water from Exploration drill hole, North Freedom, Analyst, G. M. Davidson, April 7th, 1904.
7. Water from Exploration drill hole, North Freedom, Analyst, W. W. Daniells, Bull. No. 13, Wis. Geol. Nat. Hist. Sur. p. 111, 1904.
8. Water from Oliver Iron Mine, North Freedom, Analyst, W. W. Daniells, Bull. No. 13, Wis. Geol. Nat. Hist. Sur., p. 111, 1904.
9. Water from Illinois Iron Mine, North Freedom, Analyst, W. W. Daniells, Bull. No. 13, Wis. Geol. Nat. Hist. Sur., p. 111, 1904.
10. Water from Illinois Iron Mine, North Freedom, Analyst, W. W. Daniells, Bull. No. 13, Wis. Geol. Nat. Hist. Sur., p. 111, 1904.

Sawyer County

Sawyer county, located in the northern part of the state, has an area of 1,342 square miles, and a population of 6,227. Only 5.1 per cent of the land of the county is in farms, of which only 24.2 per cent is under cultivation. The Lac Court Oreille Indian Reservation, containing about 1,000 Indians, is located in the west central part of the county.

SURFACE FEATURES

Sawyer county is a great undulating plain throughout most of its area. In the southwestern part are some relatively high ridges of quartzite. Lakes are a prominent feature of the northwestern part. The principal rivers are the Chippewa and Flambeau. The northwestern corner is drained by the Nemakagon, a tributary of the St. Croix.

The altitude of Sawyer county ranges between a little below 1,200 feet to 1,432 feet, (at Beaver Lake), along the Chippewa river, to 1,400 and 1,600 feet on the divide between the rivers. At Hayward, on the Nemakagon river, the altitude is 1,186 feet. Lac Court Oreille, the head of Couderay river, a tributary of the Chippewa, lies at an elevation of 1,287 feet.

GEOLOGICAL FORMATIONS

The principal formations are the surface deposits of glacial drift, and alluvial sand and gravel. Along the Chippewa and Flambeau rivers are numerous rapids caused by outcrops of granitic rocks. In the southwestern part are some high ridges of Pre-Cambrian quartzite formation. For the geologic section, see Fig. 23.

The surface formation is quite generally very thick throughout the county, ranging from a few feet up to 250 feet in thickness.

WATER-BEARING HORIZONS

The principal source of water supply are the deposits of sand and gravel in the surface formation. The water level is generally near the surface and abundant water can generally be obtained at depths of 15 to 40 feet in the surface deposits. Shallow open wells should be avoided as much as possible, and drilled or driven wells properly

cased to depth of 25 or 30 feet, substituted in their place. The casing should extend 15 or 20 feet below the water level to insure a pure water supply.

WATER SUPPLIES FOR CITIES AND VILLAGES

Hayward. Hayward is the county seat and principal town, with an estimated population of 2,500. It is located upon the Nemakagon river, at an elevation of 1,186 feet above sea level.

At Hayward, the city water supply, for fire protection mainly, is taken from the Nemakagon river, which is very turbid during the spring log drives. A change from the river to a spring source would be advisable, although thus far no sickness seems traceable direct to the river water supply. Wells usually are from 15 to 25 feet deep, and are usually open dug wells drawing their water from a sandy loam. There are numerous springs in this locality, and one owned by A. C. Wightman could readily supply enough water for a small town. A partial sewage system is installed, which empties into the river.

QUALITY OF THE WATER

No analyses of water from this county are at hand, but judging from the character of the geological formations, the water supplies are very probably soft and of low mineral content throughout the county.

SHAWANO COUNTY

Shawano county, located in the east central part of the state, has an area of 1,135 square miles and a population in 1910 of 31,884. About 51.4 per cent of the county is in farms, of which 44.7 per cent is under cultivation. The Menominee Indian reservation occupies a considerable area in the northern part of the county.

SURFACE FEATURES

The southeastern part of the county is somewhat hilly and rolling while the northwestern part is somewhat more level. There are two belts of terminal moraine extending across the county, one in the northwestern part, the other in the southeastern part, east of Lake Shawano. The slope of the land to the southeast is steeper in the northwestern part than in the southeastern. The general altitude of the valley bot-

tom of the Wolf river, below Shawano, is about 800 feet, while the general altitude of the northwestern part of the county ranges between 1,300 to 1,600 feet. The Wolf river which drains the principal part of the county, has a fall in its upper course of 774 feet, 9.7 feet per mile for the 80 miles between Lenox (in Oneida county) and Shawano, while between Shawano and Lake Winnebago, an equal distance of 80 miles, the total fall is only 42 feet, only a little over one-half foot per mile. Below Shawano the banks of the Wolf are low, and in high water the surrounding flats are often overflowed for several miles in width.

The soils are mainly loams with a belt of sand and sandy loam along the Wolf river south of Shawano.

GEOLOGICAL FORMATIONS

That part of the county west of Wolf river and north of Lake Shawano is underlain with Upper Cambrian (Potsdam) sandstone and the Pre-Cambrian crystalline formations, while in the southeastern part of the county, the outcropping rock is the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, the St. Peter sandstone, and the Galena-Platteville (Trenton) limestone. These rock formations are overlain with a variable thickness of glacial drift on the uplands and of alluvial deposits in the valleys. (See section Fig. 67).

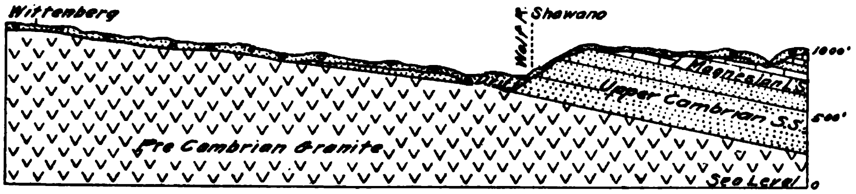

Fig. 67.—Geologic section, east-west, across Shawano County.

The thickness of the rock formations is quite variable on account of the unequal erosion of the formations, the complete thickness being present only where the formation has been protected from erosion by the overlying strata. The approximate range in thickness of the geological formations in the county may be summarized as follows:

Approximate range in thickness of formations in Shawano County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Galena-Platteville (Trenton) limestone	0 to 100
St. Peter and Lower Magnesian	0 to 200
Upper Cambrian (Potsdam) sandstone	0 to 500
Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing formations are the surface deposits of drift and alluvial sand, and the Upper Cambrian sandstone. In the northwestern part many farm wells draw their supply from the granite, and in the southeastern part, southeast of Lake Shawano, the limestone formations are drawn upon.

The water level is usually not far below the surface, an abundant supply being obtained generally at depth of less than 100 feet.

FLOWING WELLS

Flowing wells in surface deposits occur in Cecil at the east end of Lake Shawano. While the water in the sandstone underlying the Trenton limestone in the southeastern part of the county is under pressure, the altitude is too high to obtain artesian wells flowing above the surface. A shallow flowing well at Wittenberg is developed in fractured granite overlain by water-bearing gravel.

WATER SUPPLIES FOR CITIES AND VILLAGES

Shawano. Shawano, located on the Wolf river, has a population of 2,923. The city water supply is obtained at present from twenty-eight 2-inch drive wells. The wells are 21 feet deep and the well points are 4 feet long. The wells are located in two parallel rows with a spacing of 14 feet. Under a suction of 11 feet the wells supply 320 gallons per minute. This supply is inadequate for the needs of the city and at present a new system of supply obtained from deeper wells is being installed. The test wells put down in 1909 for this purpose struck the granite at 135 and 142 feet after passing through surface sand and gravel. The waters stands at 8 feet below the surface at the water station. The average daily pumpage is about 90,000 gallons. Only about 25 per cent of the houses are connected with the water supply. Many private wells in the city are from 10 to 30 feet deep in the sand and gravel. The city sewage, without purification, empties into the river.

Wittenberg. The population of Wittenberg is 1,090. At Wittenberg most of the wells are open dug wells and range in depth from 10 to 60 feet, depending entirely upon location. A few are from 100 to 150 feet deep. On the hill one-fourth mile southwest of the railroad station and about 50 feet above it, on the property of the Wittenberg Academy, is probably the deepest well in the granite.

Section of well at Wittenberg Academy.

Formation.	Thickness.
	Feet.
Clay, dug 4 feet square	56
Gravel, dug 4 feet square	6
Granite (5-inch drill hole)	223
Total	285

The water is of excellent quality, although limited in quantity, for under the present arrangement, only about 17 barrels or 500 gallons can be pumped from the well at a time.

The dug wells at the Wittenberg Indian School, west of the station are typical drift wells of moderate depth, 30 to 50 feet.

At the Wittenberg creamery is one of the flowing wells from granite rock, the only one of its kind in the vicinity. The wells after passing through blue clay to a depth of 29 feet struck granite, from which the water supply is obtained.

Cecil.—In the village of Cecil at the east end of Lake Shawano, population 351, there are seven flowing wells reported from 30 to 40 feet deep in sand and gravel. The maximum head is 5 feet above ground. The artesian slope is developed in alluvial formation similar in character and origin to the artesian conditions in the valley of the Fox and the Rock rivers. (See pages 90–7).

Pulaski.—The log of the C. & N. W. Ry. well at Pulaski station, as interpreted from samples by F. T. Thwaites, is as follows:

Log of well of C. & N. W. Ry. Co. at Pulaski.

Formation.	Thickness.
	Feet.
Pleistocene.	
Reddish and grayish drift	34
Galena-Platteville.	
Brownish limestone	39
Bluish shaly limestone	7
Bluish gray limestone	40
Lower Magnesian.	
Grayish limestone	120
No sample	14
Total	254

QUALITY OF THE WATER

The mineral analyses of various surface and well waters in the county are shown in the following table. The river waters analyzed are of low mineral content, though a little too high in lime and magnesia to be classed as soft waters. The railroad well at Pulaski, in the limestone, is a hard calcium carbonate water, such as is usually found in this formation. The analysis of the city water supply of Shawano, with its high content of chlorine, and the undetermined soluble matter very apparently indicates a contaminated water supply at the time sample was taken.

The water from the West Branch of the Embarrass river at Tigerton, No. 1, contains 1.07 pounds of incrusting solids in 1,000 gallons, and that from the railroad well at Eland Junction, No. 4, contains 2.29 pounds in 1,000 gallons.

Mineral analyses of water in Shawano County.

(Analyses in parts per million)

	Rivers.			Surface deposits.			Galena and Platteville limestone.
	1.	2.	3.	4.	5.	6.	7.
Depth of well..........feet..	....	....	....	23	15	....	254
Silica (SiO_2)..................	7.3	13.3	15.2	11.9	9.9	8.0	19.7
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)............	0.6	....	0.5	1.0	1.3	2.4	1.0
Calcium (Ca)................	25.3	35.7	18.1	60.6	77.0	30.3	51.1
Magnesium (Mg)............	12.6	....	21.4	28.5	28.6	18.4	31.4
Sodium and potassium (Na+K)....................	3.5	8.6	7.0	5.	22.3	6.9	14.9
Carbonate radicle (CO_3)....	48.0	47.6	80.1	141.9	123.9	92.5	154.1
Sulphate radicle (SO_4)......	33.9	31.9	2.5	30.6	98.9	12.5	9.9
Chlorine (Cl)................	5.5	11.5	8.9	8.9	33.3	10.6	14.1
Organic matter..............	26.2	64.3	37.2	....	....	....	....
Undet. sol. matter..........	....	....	....	....	90.8	....	....
Total solids..............	137.	148.	154.	288.	395.	181.6	296.

1. Pond on West Branch of Embarass River, Tagerton, Analyst, G. M. Davidson, July 16, 1909.
2. Branch of Embarass River at Eland Junction, Analyst, G. M. Davidson, Sept. 7, 1900.
3. North branch, Embarass River at Bowler, Analyst G. M. Davidson, Aug. 6, 1907.
4. Well of C. & N. W. Ry. Co., Eland Junction, Analyst, G. M. Davidson, Feb. 5, 1896.
5. Wells of city water supply, Shawano, Analyst, G. M. Davidson, Mar. 26, 1908.
6. Well at Shawano, Analyst, Mil. Ind. Chem. Institute.
7. Well of C. & N. W. Ry. Co. at Pulaski, Analyst, G. M. Davidson, July 22, 1907.

SHEBOYGAN COUNTY

Sheboygan county, located in the eastern part of the state, on Lake Michigan, has an area of 540 square miles and a population of 54,888. About 91.8 per cent of the county is laid out in farms, of which 74.2 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is an undulating plain sloping down towards Lake Michigan. The slope is relatively uniform throughout the county, the highest land being in the west central part, west of Plymouth.

The principal drainage line is the Sheboygan river with its tributaries, the Mullet and Onion rivers. The southwestern part of the county south of the high upland is drained by the headwaters of the Milwaukee river.

The valleys and uplands are broad and gently sloping and have a tendency to trend in a northeast-southwest direction parallel to the lake shore. In the western part of the county is a belt of hummocky drift hills generally known as the Kettle Range.

Elevations range from a little below 600 feet above sea level adjacent to the lake to over 1,200 feet in the northern part of the town of Mitchell and adjacent part of Greenbush. Definite information is not available but it seems quite probable that many high points along the Kettle Range may reach altitudes of 1,100 to 1,200 feet. The shores along Lake Michigan are steep and usually 40 to 60 feet high. The most prominent reliefs lie in the central and western parts of the county where differences in elevation between valley bottom and adjacent ridges range between 200 and 300 feet.

GEOLOGICAL FORMATIONS

The geological formations that appear at the surface in Sheboygan county are the superficial deposits of glacial drift and associated lacustrine formations, and the underlying rock formation of Niagara limestone.

The drift as usual is of variable thickness and consists of clay, sand, gravel and boulders. Outside of the belt of drift hills in the Kettle Range the drift is usually from 20 to 100 feet thick. In the morainic ridges of the Kettle Range there are many wells 180 to 200 feet deep that do not reach the rock.

The thickness of the Niagara limestone in Sheboygan county is apparently greater than it is in any other part of Wisconsin. This fact is indicated by the records of the deep wells bored through this formation at Sheboygan Falls and at Sheboygan, in which thicknesses of 538 feet and 719 feet, respectively, were penetrated. At Plymouth a thickness of 422 feet is reported but it is not known whether the entire formation was drilled through. At Mt. Calvary, a short distance west of the northwest part of the county, the thickness of the Niagara is 231 feet.

The minimum thickness of the Niagara in Sheboygan county, probably occurring in the northwestern part, may be about 200 feet while the maximum thickness adjacent to Lake Michigan is over 700 feet. With reference to the maximum thickness, the possibility should perhaps be taken into consideration that the unusual thickness in Sheboygan may not comprise the Niagara alone but may be due to the occurrence of Devonian limestone overlying the Niagara, such as that occurring a short distance farther south at Lake Church in Ozaukee county. In this connection it is of interest to note that the deep well at Sheboygan Falls, only six miles west of Sheboygan shows a thickness of 538 feet of Niagara, while the first deep city well at Two Rivers, 30 miles north of Sheboygan, shows a thickness of only 280 feet of the Niagara. The general thickness of the formations in Sheboygan county, indicated by the deep wells at Sheboygan Falls and Sheboygan may be summarized as follows:

Thickness of geological formations in Sheboygan County.

Formation.	Thickness
	Feet.
Surface formation	0 to 250
Niagara limestone (probably including some Devonian)	200 to 750
Cincinnati shale	200 to 250
Galena-Platteville (Trenton) limestone	200 to 250
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	600 to 700
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The principal sources of the underground water supply are the surface deposits of drift and the Niagara limestone. The drift contains seams and beds of sand and gravel which are usually filled with abundant water at depths of less than 100 feet from the surface. In the drift of the Kettle Range, however, west of Plymouth some of these

wells are 180 to 200 feet deep. It is quite common to find sufficient water in the drift on the slopes of the hills in open dug wells from 20 to 30 feet deep. Drilled wells, however, generally go to depths of about 100 feet to obtain a sufficient supply at the permanent water level.

Many of the drift wells have been deepened by drilling and now obtain their water supply near the contact of the rock and overlying drift or from a short distance into the limestone. The limestone contains beds of shaly formation, relatively impervious, and the shaly strata have a strong influence in controlling the underground supply. Abundant water can usually be obtained in the limestone at depth of less than 100 feet on the slopes. In the valleys the water level is near the surface in both the drift and the rock.

FLOWING WELLS

Flowing wells are obtained from the drift, from the Niagara limestone, and from the deep seated strata of St. Peter and Potsdam sandstones.

Along the Sheboygan river and its tributaries as far west as Plymouth and some distance beyond, flows are obtained at various places, the source of the flows being in gravel seams below clay beds.

In the valley of Pigeon river in the towns of Meeme, Manitowoc county, and Herman, Sheboygan county are a large number of good flowing wells in the drift which are used extensively for farm purposes. Most of these wells are drilled, and range in depth from 30 to 75 feet.

They have comparatively small flows, usually rising less than 5 feet above the surface, and draw their water from beds of sand and gravel between layers of impervious clay. In the vicinity of Cedar Grove, near the shore of Lake Michigan, are several strong flowing wells in the drift, the strongest having a flow of 30 feet above the surface.

The city well of Plymouth draws its supply from a depth of 422 feet in the Niagara limestone, the head being 16 feet above the ground. There are doubtless many other flowing wells in the county that draw their supply from this formation, though definite information concerning them is not now at hand. Some of the flowing wells in the drift may receive their supply from the underlying Niagara and an increase in the flow could be obtained if drilled deeper. Conditions, however, are likely to be variable because both these types of flowing wells are due to local conditions of the topography and rock formations.

Flowing wells in the deep seated strata of St. Peter and Upper Cambrian (Potsdam) sandstone have been obtained at Sheboygan Falls and Sheboygan, as described under these cities on the following pages. The

normal head of the deep flowing well at Sheboygan when first drilled was 104 feet above the surface, or 146 feet above the lake, the first flow being struck in the St. Peter sandstone at depth of 1,340 feet. The well at Sheboygan Falls, 1,200 feet deep, probably obtains its flow from the St. Peter sandstone.

The chance for obtaining artesian flows from the St. Peter and Upper Cambrian (Potsdam) formations in Sheboygan county are good up to elevations of at least 200 feet above Lake Michigan, and are fair up to 250 feet, and may be possible, in some places, above 250 feet. Localities favorable for deep-seated flows are generally confined to a narrow belt, 3 or 4 miles from the lake shore, but may also extend much farther up the Sheboygan river to the mouth of the Mullet, a distance of about 13 miles. The artesian head rises rapidly to the west, and hence flows from the sandstone may be found at still higher elevation.

SPRINGS

Springs are quite common along the foot of the drift hills of the Kettle Range in the western part of the county. They also occur along many of the valeys where rock ledges are abundant.

Mineral water from the deep well in Sheboygan, which furnishes a strong saline water, is sold on the market and is also used for bathing purposes. (See table of analyses).

WATER SUPPLIES FOR CITIES AND VILLAGES

Sheboygan. The city of Sheboygan, on Lake Michigan at the mouth of Sheboygan river, has a population of 26,398. The city water supply is obtained from Lake Michigan, from 3 intakes located some distance from shore at depths of 12, 27 and 46 feet. The average daily pumpage is reported to be 3,526,000 gallons. The sewerage without purification empties into the lake. About 50 per cent of the houses are connected with the water and sewer systems.

In the city well drilled in 1875, as reported by Prof. Chamberlin,[1] the material passed through is as follows:

[1] Geology of Wisconsin, vol. 2, p. 164.

Section of Sheboygan City Well.

Formation.	Thickness.
	Feet.
Drift	92
Niagara limestone	719[1]
Cincinnati shale	240
Trenton and Galena	213
St. Peter sandstone	212
Total depth	1,476

[1] This thickness of Niagara may include some Devonian overlying the Niagara.

It was reported that granite was struck in the city well, but this is very doubtful since the well drilled at Schreier's Brewery did not reach granite at a depth of 1,782 feet. The water from both of these deep wells is decidedly salty and corrodes the pipe very readily. The well casing at the brewery has not been lined with copper, and the pipe is now corroded so that there is considerable leakage. Many of the more shallow wells have subsequently been abandoned because the leakage at the brewery well has made the water salty. No record was kept of the brewery well, but it is reported that the well passed through sandstone immediately below the St. Peter, and hence, the limestone of the Lower Magnesian horizon is apparently absent in this locality.

The water from the old city well is reported to have a uniform temperature of 60° F., and is now bottled and sold extensively for medicinal purposes and also as a table water by the Sheboygan Mineral Water Company. This company was established in February 1876, and incorporated under the laws of Wisconsin in November 1881. There is a pipe line from the city well to its bottling establishment. For mineral analysis see Nos. 26 to 30 in the table.

Sheboygan Falls. The population is 1,630. The water supply is obtained from private wells, generally from 20 to 100 feet in the drift. The deep artesian well of H. Giddings has the following section:

Section of H. Giddings' well, Sheboygan Falls.

Formation.	Thickness.
	Feet
Drift	117
Niagara limestone	478
Cincinnati shale	265
Galena Trenton limestone	330
St. Peter sandstone	10
Total depth	1200

The altitude of the curb is 718 feet, the artesian pressure being sufficient to develop a head 55 feet above the curb. The source of the flow is probably the St. Peter sandstone.

Plymouth.—This city located on Mullet river has a population of 3,094. There were two wells,[1] one 127 the other 473 feet deep, in connection with the city supply in 1904 but only the deepest well was used. At present, 1914, the city supply is obtained from 4 wells, reported as 12 to 458 feet deep. About 75 per cent of the houses are connected with the water supply.

The deep well is 10.8 and 6 inches in diameter. It flowed 60 gallons per minute 16 feet above ground. In the bottom of the reservoir 16 feet deep the flow was 300 gallons per minute. A sewage disposal plant was recently installed. Sewage is treated before being emptied into the Mullet river.

The deep city well is of special interest as the source of the water found is in the Niagara limestone, the material penetrated being 51 feet of clay, sand, and gravel, and 422 feet of Niagara limestone. No effect has been noticed at the various wells in the way of interference.

Oostburg. The log of the C. & N. W. Ry. well at Oostburg, samples of which down to a depth of 454 feet are in the University collection, is as follows:

Log of C. & N. W. Ry. Well at Oostburg.

Formation.	Thickness.
Pleistocene:	Feet.
Red and blue calcareous clay containing a few pebble beds and with fine gravel at bottom	142
Niagara:	
Grayish limestone containing some shaly beds	312
No samples	96?
Total depth	550

The analysis of the highly mineralized water from this well is shown in the table as No. 18.

QUALITY OF THE WATER

The mineral analyses of various waters of the county are shown in the following table. The character, as well as the amount of mineralization, is quite variable. Carbonate, sulphate, and chloride underground waters occur, with content of mineral ranging from a little

[1] W. G. Kirchoffer, Bull. Wis. Univ. No. 106, p. 221.

over 200 parts per million in case of carbonate water, to over 10,000 parts per million in case of the chloride waters.

The surface water from the lakes and the river, as usual, are lowest in mineral content, though sufficiently high to be classed as hard waters. The water supplies from the surface deposits and the Niagara limestone are generally carbonate waters of moderate mineralization, though in places there are exceptions, as illustrated by the highly mineralized sulphate water in the 550 foot well at Oostburg. The geologic source of the water in the Oostburg well is not definitely known, but the well is reported to be in "limestone and sandstone", probably reaching the base of the Niagara and top of the Cincinnati shale.

The deep seated waters from wells 1,038 to 1,476 feet deep, which reach into the St. Peter and Lower Magnesian sandstones, are very highly mineralized with salt water at Sheboygan and Sheboygan Falls, and also highly mineralized with sulphate waters at Random Lake. The analyses and information concerning source of the water appear to indicate, therefore, that the strong saline waters in the St. Peter and Lower Magnesian may be characteristic over considerable parts of Sheboygan county. The highly mineralized waters occasionally found in the Niagara probably have their source in the more deeply lying strata of Lower Magnesian and St. Peter formations.

The analyses of the salt waters at Sheboygan Falls and Sheboygan made by G. Bode and C. F. Chandler, were made many years ago,—probably between 1870 and 1876. Those of more recent date, made in 1907 and 1909, show a much lower content of mineral, which may be due to a change in the chemical character of the original deep source of supply, or the change may be due to the infiltration of less mineralized water from higher horizons.

The water from the Born Park Sanitarium is used for bottling and bathing purposes, and that of the Sheboygan Mineral Water Co. is mainly bottled and sold.

The water from the Sheboygan river at Sheboygan, No. 1. contains 1.69 pounds of incrusting solids in 1,000 gallons; that from the well in Plymouth, No. 16, contains 3.10 pounds in 1,000 gallons, while that from the well at Oostburg, No. 18, contains 7.39 pounds in 1,000 gallons.

Mineral analyses of water in Sheboygan County.

(Analyses in parts per million)

	River.	Lakes.				
	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	10.6					
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	2.9	0.8	Undt.	2.4	Undt.	2.1
Calcium (Ca)	37.1	34.0	44.6	41.7	54.4	28.7
Magnesium (Mg)	26.8	23.6	37.9	34.8	36.9	31.1
Sodium (Na) / Potassium (K)	6.0	3.8	3.1	3.8	4.7	2.9
Carbonate radicle (CO_3)	93.5	107.7	159.5	140.3	172.4	117.8
Sulphate radicle (SO_4)	35.5	6.4	6.5	11.5	9.9	4.7
Chlorine (Cl)	20.1	2.1	Undt.	5.0	Undt.	2.3
Organic matter	13.6	....	....	....	....	....
Total dissolved solids	232.	178.	252.	239.	278.	190.

	Lakes.		Surface deposits.			
	7.	8.	9.	10.	11.	12.
Depth of well ... feet	....	....	8.	15	15	15
Silica (SiO_2)		11.1				
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	Undt.	1.6	9.2	4.9	1.0	Undt.
Calcium (Ca)	31.7	21.1	66.5	98.6	68.4	70.2
Magnesium (Mg)	31.1	24.3	35.6	30.9	39.4	40.6
Sodium (Na)	2.7	4.1	5.9	22.9	12.0	8.1
Potassium (K)		2.2				
Carbonate radicle (CO_3)	117.8	86.5	186.8	202.2	189.4	179.1
Sulphate radicle (SO_4)	6.3	....	8.6	36.2	19.1	56.3
Chlorine (Cl)	6.1	11.6	2.0	33.6	18.5	Undt.
Organic matter	....	5.7	....	....	....	....
Total dissolved solids	196.	168.	315.	429.	348.	354.

1. Sheboygan River at Sheboygan. Sample taken from reservoir, Analyst, G. M. Davidson, Sept., 1900.
2. Random Lake, Analyst, Chemist, C. M. & St. P. Ry. Co., June 29, 1892.
3. Random Lake, Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 20, 1900.
4. Random Lake, Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 24, 1901.
5. Spring Lake near Random Lake, Analyst, Chemist, C. M. & St. P. Ry. Mar. 20, 1900.
6. Lake Elkhart, Analyst, Chemist, C. M. & St. P. Ry. Co., May 28, 1899.
7. Lake Elkhart, Analyst, G. N. Prentiss, April, 1908.
8. Elkhart Lake, mean of four analyses at various depths, Analyst, E. B. Hall and C. Juday, Sept. 12, 1908, Wis. Sur. Bull. 22, p. 170.
9. Spring and well of C. M. & St. P. Ry. Co., Plymouth, Analyst, Chemist, C. M. & P. Ry. Co., July 9, 1891.
10. Well of C. M. & St. P. Ry. Co., Random Lake, Analyst, Chemist, C. M. & St. P. Ry. Co., July 13, 1891.
11. Well of C. M. & St. P. Ry. Co., Random Lake, Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 24, 1901.
12. Well of C. M. & St. P. Ry. Co., Random Lake, Analyst, G. M. Prentiss, Nov. 27, 1900.

Mineral analyses of water in Sheboygan County—Continued.

	Surface deposits.		Probably Niagara limestone.			
	13.	14.	15.	16.	17.	18.
Depth of well .... feet..	30	42	208	96	135	550
Silica (SiO)..s............				16.9		9.9
Aluminium and iron oxides (Al_2O_3+Fe_2O)	Undt.	Undt.	Undt.	1.0	8.0	1.7
Iron (Fe)	....	....	....	....	2.7	....
Calcium (Ca)	97.2	109.9	34.2	79.0	32.7	180.5
Magnesium (Mg)	59.2	41.8	35.6	43.0	18.7	60.5
Sodium and potassium (Na+K)	38.7	38.8	25.8	9.7	23.4	76.3
Carbonate radicle (CO_3)	226.6	220.2	162.6	208.0	79.5	67.2
Sulphate radicle (SO_4)	180.2	38.1	2.3	24.5	28.0	715.5
Chlorine (Cl)	Undt.	86.7	9.1	14.9	34.2	5.7
Undet. sol. matter	....	....	....	....	....	62.8
Total dissolved solids	602.	535.	270.	397.	227.	1117.

	St. Peter and Lower Magnesian formations.					
	19.	20.	21.	22.	23.	24.
Depth of well .... feet..	1,000	1,000	1,038	1,038	1,038	1,038
Silica (SiO_2) .... Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	4.7	1.5	0.3	Undt.	Undt.	Undt.
Calcium (Ca)	100.5	91.4	90.3	174.6	277.0	125.2
Magnesium (Mg)	43.8	41.3	41.1	61.2	75.4	51.4
Sodium (Na) .... Potassium (K)	28.9	19.1	15.0	193.2	8.4	28.6
Carbonate radicte (CO_3)	222.9	197.0	183.7	150.0	152.6	180.4
Sulphate radicle (SO_4)	57.9	67.2	84.2	820.0	738.1	273.6
Chlorine (Cl)	44.5	28.5	23.3	Undt.	Undt.	....
Total dissolved solids....	503.	446.	438.	1,399.	1,246.	659.

13. Private well 100 feet east of Random Lake Station, Analyst, G. N. Prentiss, Mar. 20, 1900.
14. Well at Elkhart Lake, Analyst, G. N. Prentiss, May 19, 1908.
15. Well at Elkhart Lake, Analyst, G. N. Prentiss, Aug. 14, 1908.
16. Well of C. & N. W. Ry. Co., Plymouth, Analyst, G. M. Davidson, June 18, 1895.
17. Well of Sheboygan Knitting Co., Sheboygan, Analyst, Chemist, C. M. & St. P. Ry. Co.
18. Well at Oostburg, 100 feet north of station, Analyst, G. M. Davidson, May 20, 1909.
19. Well of C. M. & St. P. Ry. Co., Random Lake, Analyst, G. N. Pentiss, June 25, 1892.
20. Well of C. M. & St. P. Ry. Co., Random Lake, Analyst, G. N. Prentiss, June 10, 1892.
21. Well of C. M. & St. P. Ry. Co., Random Lake, Analyst, G. N. Prentiss, May 20, 1896.
22. Deep well and reservoir of C. M. & St. P. Ry. Co., Random Lake, Analyst, G. N. Prentiss, Feb. 7, 1900.
23. Deep well and reservoir of C. M. & St. P. Ry. Co., Random Lake, Analyst, G. N. Prentiss, Mar. 20, 1900.
24. Deep well and reservoir at C. M. & St. P. Ry. Co., Random Lake, Analyst, G. N. Prentiss, April 24, 1900.

Mineral analyses of water in Sheboygan County—Continued.

	St. Peter and lower Magnesian formations.					
	25.	26.	27.	28.	29.	30.
Depth of well........ feet..	1,200	1,476	1,402	1,476	1,476	....
Silica (SiO_2)........ Aluminium and iron oxides (Al_2O_3+ Fe_2O_3)........	26.3	79.6	2.3	15.8	5.2	13.
Aluminium oxide (Al_2O_3)........	5.5	2.1	....	81.6	.1	18.9
Iron (Fe)........	3.2	2.7	....	0.6	.3	4.7
Calcium (Ca)........	1,042.8	1,083.2	1,107.	341.6	203.	1,065.2
Magnesium (Mg)........	198.2	239.4	759.5	81.3	59.4	310.6
Sodium (Na)........	1,429.4	2,063.4	1,592.	896.4	864.	2,484.3
Potassium (K)........	52.5	129.7		169.3	3.3	88.5
Lithium (Li)........	....	.2	....	....	....	.07
Carbonate radicle (CO_3)........	197.8	90.4	883.	9.8	207.	121.1
Sulphate radicle (SO_4)........	1,732.7	2,050.1	2,051.	673.	514.5	2,150.
Chlorine (Cl)........	3,137.5	4,309.0	4,037.	1,272.	1,218.	5,099.
Bromine (Br)........	6.6	2.4	....	....	....	14.
Iodine (I)........	....	Trace.	....	....	....	0.34
Iron oxide (Fe_2O_3)........	....	....	8.6	....	....	....
Total dissolved solids........	7,833.	10,052.	10,440.	3,541.	3,075.	11,370.

25. Well of H. Giddings, Sheboygan Falls, Analyst, G. Bode, Geol. of Wis.
26. City park well at Sheboygan. Analyst. C. F. Chandler, Geol. of Wis., Vol. 2, p. 165.
27. Born Park Sanitarium well, Analyst, Chicago Clin. & Anal. Laboratory.
28. Well of Sheboygan Mineral Water Co., Sheboygan, Analyst, State Hygienic Lab. Aug., 1909.
29. Well of Sheboygan Mineral Water Co., Sheboygan, Analyst Richard Fisher, Feb. 1907.
30. Artesian well at Sheboygan, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 89.

TAYLOR COUNTY

Taylor county, located in the north central part of the state, has an area of 965 square miles, and a population of 13,641. About 21.5 per cent of the county is laid out in farms, of which 24.8 per cent is under cultivation.

SURFACE FEATURES

The surface of the county, with a few exceptions, is a gently undulating plain. A belt of drift hills extends from the southwestern part of the county to the northeastern, the drift hills rising from 100 to 150 feet above the general level in the area, northeast of Westboro and north of Rib Lake. The altitude generally lies between 1,400 and 1,600 feet. The principal drainage lines are the Yellow and Jump rivers, flowing southwest towards the Chippewa, the Black river flowing south, and the Rib river, a tributary of the Wisconsin, flowing southeast. The soil is mainly a silt loam or sandy loam throughout the entire county.

GEOLOGICAL FORMATIONS

The principal geological formation is glacial drift, consisting of a heterogeneous mixture of clay, sand and gravel mixed with boulders. In only a few localities are there outcrops of granite rocks along the river beds. The drift is usually quite thick, ranging from 50 to 200 feet.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing horizon is the surface formation of drift, in which an abundant supply can usually be obtained at relatively shallow depths. Most of the wells in the southeastern part of the county range in depth between 20 and 40 feet.

At Stetsonville the wells are generally from 12 to 30 feet deep, the deepest one, at the mill, being 50 feet deep, wholly in drift. At Chelsea, wells are from 12 to 30 feet deep in sandy drift. At Westboro, the deepest well, 50 feet deep, is wholly in the drift.

WATER SUPPLIES FOR CITIES AND VILLAGES

Medford. Medford, the county seat of Taylor, has a population of 1,846. It is located on the Black river, the elevation of the railroad station being 1,408 feet above sea level. The topography is uneven, the principal part of the city being on the east slope of the river valley. The formation is wholly drift, of clayey, sandy and gravelly character. The surface soil is generally a clay loam. Granite is struck at a depth of 50 or 65 feet at the Shaw tannery. Wells on the east side of the valley, on the upper slope, are 80 feet in drift, and upon the hill 140 feet in drift without striking rock. Many wells in the valley bottom are only from 10 to 30 feet deep, and are in danger of contamination. Formerly the public supply, used for fire purposes only, was obtained from the Black river. The present public water supply is obtained from a system of 11 wells, located near the river, each well being 12 inches in diameter and 40 to 60 feet deep, depending upon the depth to the granite. Nine of the wells are located near the pumping station, and two, about one-fourth mile up the river, on the west side, at the site of a spring. The daily capacity of the system is about 570,000 gallons. About 25 per cent of the houses are connected with the water system. A partial sewage system is installed for the public buildings and the main street. The sewage is emptied, without treatment, into the Black river.

Rib Lake. This village has a population of 1,018, and is located on the west bank of Rib Lake. The elevation of Rib Lake is 1,556 feet above sea level. The formation is glacial drift, with sandy loam surface soil and sandy gravelly drift subsoil. Most of the private wells in the village are from 10 to 30 feet deep. One deep well at the hotel is 130 feet deep, wholly in the drift. The city water supply, used for fire protection only, is obtained from Rib Lake through a 12 inch intake reaching about 50 feet from the shore.

QUALITY OF THE WATER

No complete analyses of the waters of Taylor county are available. The surface water supplies from lakes and rivers are likely to be very soft or soft water low in mineral content. The ground water supplies are usually higher in mineral content than the surface supplies but are likely also to be soft water with only a few occurrences of hard water. A partial analysis of the railroad supply at Medford shows a total mineral content of 9.27 grains per gallon of dissolved solids, or 160 parts per million, indicating a hard water.

TREMPEALEAU COUNTY

Trempealeau county, located in the western part of the state, has an area of 734 square miles, and a population of 22,928. About 94.2 per cent of the county is in farms, of which 57.8 per cent is under cultivation, being fairly uniformly well settled over the entire county.

SURFACE FEATURES

The topography is uneven, the surface features consisting of upland slopes and valley bottoms. Loess loam soils are common over the uplands, and sandy alluvial soils on the slopes and in the bottoms.

The altitudes range between less than 700 feet along the Mississippi and the lower Trempealeau and Black rivers to 1,100 and 1,200 feet on the level topped uplands. The valley bottom of the Beef river in the northern part is at an altitude mainly between 800 and 900 feet. The steep sided valley of the Beef river in the northern part of the county and of the Trempealeau in the eastern and central part are prominent features. The high bluffs along the Mississippi, rising abruptly 300 to 400 feet, are also striking features of the topography.

GEOLOGICAL FORMATIONS

The geological formation is mainly the Upper Cambrian (Potsdam) sandstone, only the highest divides in the county being capped by the Lower Magnesian limestone. A very small amount of glacial drift occurs in the northeastern part of the county. The geological structure is illustrated in Fig. 41, p. 375.

The alluvial filling of silt, sand and gravel in the valleys probably reaches a maximum thickness of 150 to 200 feet. The thickness of the Upper Cambrian (Potsdam) sandstone and Lower Magnesian limestone, as encountered in the wells of various parts of the county, varies greatly on account of the extensive erosion of the strata. It is only where the Upper Cambrian sandstone is overlain by the Lower Magnesian limestone that the complete thickness of the former is preserved. The limestone occurs, as already stated, only on the highest dividing ridges. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Trempealeau County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 200
Lower Magnesian limestone	0 to 50
Upper Cambrian (Potsdam) sandstone	200 to 800
The Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing horizons are the "Potsdam" sandstone and the alluvial sands and gravels filling the valleys. As both these horizons are excellent water-bearing strata, an abundant supply is readily available. Wells in Decora Prairie draw their supply at 20 to 100 feet in sand and gravel. In the valley bottoms the wells are relatively shallow, but on the uplands the wells are often from 200 to 300 feet deep.

FLOWING WELLS

Flowing wells in the Upper Cambrian (Potsdam) sandstone occur along the Trempealeau river as far up the river as Whitehall. The wells generally have a head less than 10 feet above the surface. In this

valley the granite probably lies at depth of about 400 feet below the surface, being about 375 feet at Arcadie, and probably over 400 feet at surface, being about 375 at Arcadia, and probably over 400 feet at Whitehall. Artesian wells were recently developed in the Beef valley.[1]

It is probable that flowing wells could be obtained on low ground along the Black river and also along the Mississippi, as well as up some of the small tributary valleys. In the tributary valleys the water in the alluvial deposits, where overlain by silts and clays, may be under sufficient pressure to produce artesian flows. The flowing wells in Arcadia, Whitehall and Galesville are referred to in the following description of city water supplies.

WATER SUPPLIES FOR CITIES AND VILLAGES

Arcadia. This village, located on the Trempealeau river, has a population of 1,212. The city water supply is from a well 376 feet deep, 8 inches in diameter, being cased 76 feet to sandstone. This well is reported to have reached granite. The capacity is 347 gallons per minute. The average daily pumpage is 40,000 gallons. About 40 per cent of the houses are connected with the supply. The sewage is emptied, without purification, into the Trempealeau river.

Records of deep flowing wells in Arcadia.

Owner.	Drilled.	Diameter. Inches.	Depth. feet.	Water rises above curb. feet.	Flows.	Temp. F.	Remarks.
City Water.......	1902	8	376	12	....	....	Cased 76 feet. (reached granite)
W. P. Massuers..	1897	3	330	2	1 in stream.	48	Cased 82 feet.
T. Barry.........	1898	3	288	3	1 in stream.	48	Cased 120 feet.
J. Beveridge.....	1901	3	300	5	1 in stream.	48	Cased 80 feet.
O. Hohmann.. .	1890	3	300	3	1 in stream.	48	Cased 86 feet.

One hour of pumping at the well of the city waterworks decreased the heads in all the other wells and stopped for a time the flow at Barry's and Hohmann's wells.

[1] During 1913 and 1914 numerous flowing wells were developed in the Beef river valley, in and near Eleva and Strum. The village well at Strum, altitude of curb about 848 feet, flows about 4 inches above the curb, which is 18 to 20 feet above the river level. The depth is 310 feet,—130 feet of alluvial sand, and 180 feet of sandstone, reaching granite. Other flowing wells in Strum are owned by P. H. Moltzau, 260 feet deep, 90 ft. sand, 170 ft. sandstone, artesian head 10 feet above curb, and by P. Christensen, 320 feet deep, drilled a few feet into granite.

Several other flowing wells have been drilled in Arcadia and in the neighboring country along the Trempealeau river. The common wells are from 6 to 100 feet in depth, and draw their supply from the alluvial sands over the Upper Cambrian sandstone, or from the sandstone.

Whitehall. Whitehall, located on the Trempealeau River, has a population of 703. It has a city water supply from an artesian well 216 feet deep, 100 feet to the Potsdam sandstone being cased. The diameter of pipe is 5 inches and the water rises 11 feet above the curb. The pumping capacity is 350 gallons per minute.

The water drops about 20 feet in the city well during heavy pumping, but has never dropped as low as the bottom of the suction pipe, which is 25 feet deep.

At David Wood's, 40 rods north of the river, a well was sunk through 123 feet of sand, and 141 feet of Potsdam sandstone. The head here, 4 feet above surface, as indicated by the aneroid barometer, is about 790 feet above sea level.

Common wells are from 20 to 40 feet in depth, a few enter rock, the water level lying from 10 to 30 feet below the surface. Flows may also be obtained further up the Trempealeau river.

Independence. At Independence, population 664, the same kind of wells are drilled as at Arcadia and Whitehall. The Potsdam sandstone, no doubt, should give artesian flows here on the low ground, just as at Arcadia and Whitehall, and furnish an abundant supply for city purposes. The village has a public water supply, obtained from four wells, each 50 feet deep in the sand. The city sewage is emptied, without purification, into the Trempealeau river.

Galesville. The population of Galesville is 973. Flowing wells occur at Galesville, on the banks of Beaver creek, one of the flowing wells being 410 feet deep, striking the sandstone at 100 feet, and having a head of 4 or 5 feet above the surface. The wells in this vicinity are usually from 70 to 130 feet in depth and get their supply from alluvial sand or the underlying sandstone. Several springs are also found in this vicinity. The city supply is used mainly for fire protection. The supply is obtained from two 6-inch wells, 200 feet deep, and from Beaver creek. A partial sewage system is installed, the sewage being emptied into the creek.

Blair. The village well at Blair is 30 feet deep, in sand and rock, and 10 feet in diameter. About 90 per cent of the houses are connected with the public supply, the average daily pumpage being 16,000 gallons. Private wells are generally from 20 to 30 feet deep in the sand.

QUALITY OF THE WATER

The mineral analyses of the water supplies in Galesville are shown in the table. The supplies analyzed are obtained from the sandstone and are hard waters of moderate mineral content. The above analyses probably represent average waters obtained from the surface sands and the sandstone formations. Waters from the limestone uplands are very probably only slightly higher in mineral content.

The water from the city wells in Galesville, No. 3, contains 1.61 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Trempealeau County.

(Analyses in parts per million)

	Spring.	Upper Cambrian (Potsdam) sandstone.	
	1.	2.	3.
Depth of well ... feet	....	65	200
Silica (SiO_2)	1.0	4.9	16.4
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	....	1.8
Aluminium oxide (Al_2O_3)	2.6	3.6	....
Iron (Fe)	1.4	14.3	....
Calcium (Ca)	57.6	27.5	37.1
Magnesium (Mg)	27.9	28.1	17.3
Sodium (Na)	5.5	18.6	2.9
Potassium (K)	1.4	....	
Carbonate radicle (CO_3)	157.1	118.2	88.9
Sulphate radicle (SO_4)	2.6	22.7	15.7
Chlorine (Cl)	8.4	1.8	4.2
Organic matter	....	8.2	....
Total dissolved solids	265.	285.	184.

1. Arctic Spring at Galesville, Analyst, W. W. Daniells.
2. Jordan Mineral well at Galesville, Analyst, G. Bode, Geol. of Wis., Vol. IV. 1882.
3. City wells at Galesville, 2 wells, 200 feet deep, Analyst, G. M. Davidson, Dec. 18, 1899.

VERNON COUNTY

Vernon county, located in the southwestern part of the state, has an area of 792 square miles and a population of 28,116. About 92.8 per cent of the county is in farms of which 53.9 per cent is under cultivation.

SURFACE FEATURES

The greater part of the county consists of a relatively high upland plain deeply dissected by valleys. The Kickapoo river which drains the eastern half of the county is a prominent valley with steep slopes

leading up to the even summitted upland. The western part of the county is drained by streams flowing into the Mississippi, mainly the Bad Axe and the Coon rivers.

The valley bottom plain along the Mississippi river has a general altitude of about 650 feet. The valley bottom of the Kickapoo ranges in altitude between about 750 feet at Reedstown to probably about 900 feet at Ontario. The altitudes on the dissected upland generally ranges between 1,200 and 1,400 feet.

The soils are generally sandy loams and silt loams on the uplands and sands, sandy loams and occasionally silt loams in the valley bottoms.

GEOLOGICAL FORMATIONS

The principal geological formation is the Lower Magnesian limestone. Along the deepest and most important valleys the Upper Cambrian (Potsdam) sandstone is present, and upon the uplands, overlying the Lower Magnesian formations in the southwestern part of the county is the St. Peter sandstone, and occasionally upon the latter on the very highest points is the Platteville (Trenton) limestone. In the valleys is the usual amount of alluvial sand formation and on the uplands is a fairly common deposit of loess loam. The geological structure is illustrated in Fig. 68.

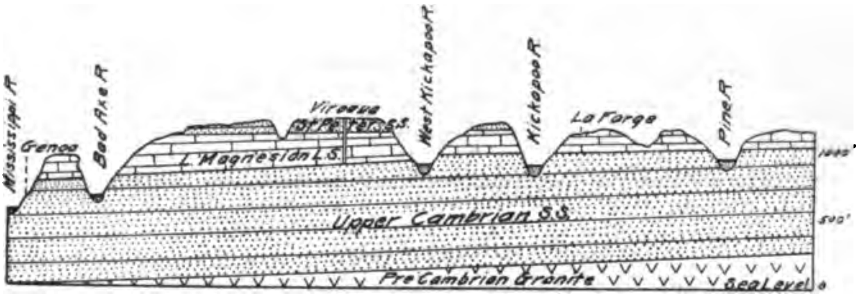

Fig. 68.—Geologic section, east-west, across central Vernon County.

The thickness of the alluvial sand and silt in the valleys is variable, but probably attains a thickness of 200 to 300 feet in the mid-channel of the Mississippi valley. The thickness of the loess upon the upland is variable, but usually does not exceed 5 or 10 feet. The thickness of the rock formation is variable on account of the extensive erosion of the strata. It is only in the highest uplands of the southwestern part of the county that remnants of the St. Peter sandstone and the Platteville (Trenton) limestone are still preserved. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Vernon County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300.
Platteville (Trenton) limestone (of rare occurrence)	0 to 40.
St. Peter and Lower Magnesian	0 to 250.
Upper Cambrian (Potsdam) sandstone	400 to 800.
The Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

The water supply is derived from all the geological formations, the most important sources being the Lower Magnesian limestone and the Potsdam sandstone. The alluvial sands and gravels are an important source of water supply in the valleys. The wells in the valleys usually reach abundant water in the sand at depth of 20 to 40 feet. The wells upon the uplands often penetrate the rock to depth of 300 to 400 feet and contain only a few feet of water.

Depth of Wells in Villages, Vernon County.

Village.	Source.	Depth in feet.
Chaseburg	Rock	200-500
De Soto	River sand and rock	15-80
Hillsboro	Rock	40-200
Lafarge	Sand	20-40
Newton	Sand and rock	20-100
Readstown	Sand rock	30-80
Rockton	Rock	75-200

FLOWING WELLS

Flowing wells are a common source of water supply along the Mississippi river. The artesian head along the Mississippi is quite uniform and is generally 50 to 60 feet above the immediately low ground, and is much as 60 or 70 feet above the level of the Mississippi river. The flows are obtained mainly if not entirely from the Upper Cambrian (Potsdam) sandstone. At Stoddard the flowing wells are generally between 400 and 550 feet deep.

The flowing wells are not confined to the banks of the Mississippi river, but are also obtained up the larger and some of the smaller tributaries of the Mississippi river. Several of these flows have been struck at Chaseburg some distance up Coon creek. The wells at Chase-

burg are from 400 to 500 feet deep and at least two flows have been obtained. In Coon Valley are 5 flowing wells 450 to 500 feet deep.

Flowing wells in the Potsdam sandstone are quite common in the Kickapoo valley. In the vicinity of LaFarge there are 6 deep flowing wells ranging in depth between 128 and 465 feet, and with heads ranging from 3 to 16 feet above the surface.

In Rockton and vicinity there are about 25 flowing wells with heads of 20 to 32 feet above the curb. In Ontario flowing wells are also a common source of water supply.

Several flowing wells have been drilled in Viola by W. P. Shilling. They are of the same general type as those above described. Farther south along the Kickapoo river at Readstown and Soldiers Grove a few deep flowing wells have been drilled. Water is generally pumped from wells 10 to 40 feet deep. Two miles east of Soldiers Grove on considerably higher ground a well 200 feet deep flows part of the time. For detailed description of artesian wells in Kickapoo valley and Coon Creek valley, see pages 70–2.

WATER SUPPLIES FOR CITIES AND VILLAGES

Viroqua. Viroqua, the county seat, has a population of 2,059. It is situated upon the high divide between the Bad Axe and Kickapoo rivers, at an elevation of 1,280 feet above sea level. The city has a water system but no sewerage system. The water supply is derived from three 8-inch wells from 200 to 559 feet deep, which penetrate through the Lower Magnesian limestone, (see Fig. 68) into the Upper Cambrian (Potsdam) sandstone, thus deriving the water supply from the latter formation. The average daily pumpage is about 100,000 gallons. About 70 per cent of the houses are connected with the water system.

Westby. Westby has a population of 902. The city water supply is obtained from two 8½-inch wells, 310 and 325 feet deep, each reaching through the Lower Magnesian limestone and penetrating the Upper Cambrian (Potsdam) sandstone about 100 feet. The estimated daily capacity is 100,000 gallons; the daily pumpage is about 18,000 gallons. Private wells are generally from 200 to 235 feet deep.

De Soto. De Soto has a public water supply obtained from a flowing well, 440 feet deep, the rate of flow being about 172,000 gallons per day. In the village are several artesian wells and a few are located north and south of the village. The wells are between 400 and 550 feet deep, wholly in the Upper Cambrian sandstone, the head being about 25 feet above the surface. It is thought that the decrease in the

heads at McAuley's and Johnson's wells, and the village wells, is chiefly because the casing was discontinued as soon as rock was entered.

At Genoa and Victory are flowing wells of the same class as those at De soto.

Stoddard.—There are a number of flowing artesian wells in this vicinity. Most of the wells are used for farm or dairy purposes. The wells are wholly in the sandstone after striking rock, and the water rises to approximately 694 feet above sea level, about 70 feet above the Mississippi river.

Hillsboro. This village has a population of 804. The city well is an 8-inch well, 149 feet deep, in the Upper Cambrian (Potsdam) sandstone. The average daily pumpage is 15,000 gallons. Private wells in the village are generally from 50 to 85 feet deep in the sandstone.

Readstown. Readstown, population 515, has a public water supply from a 6-inch well, 210 feet deep. The daily capacity of the well is 50,000 gallons. About 20 per cent of the houses connect with the city supply. Private wells are generally from 30 to 60 feet deep.

Ontario. There are about 24 flowing wells in Ontario and in the adjacent bottom of the Kickapoo valley, both up and down the stream. The shallow flows, at 80 to 90 feet in Ontario, contain less iron than the deeper flows. In the deep wells, two, three or even four strong water horizons are passed through. The same applies to wells north and south of Ontario, along the Kickapoo river.

Rockton. There are about 25 flowing wells in this vicinity. Some of the farmers have two and three flowing wells on their farms and all get water from the Potsdam sandstone. The flowing wells are found only near the river on low ground. Back nearer the hills the same water horizon is struck, but the wells do not flow.

QUALITY OF THE WATER

Only two mineral analyses of the water supplies of Vernon county are available, but judging from the character of the geological formations, hard waters of moderate mineral content are very probably prevalent throughout the county. Water obtained from the limestone strata is likely to be only slightly higher in mineral content than that from the alluvial sand and the sandstone.

Mineral analyses of water in Vernon County.

(Analyses in parts per million)

	Upper Cambrian (Potsdam) sandstone.	
	1.	2.
Depth of well......feet..	300-325	600
Silica (SiO_2)......	Undet.	Undet.
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)......		
Calcium (Ca)......	41.4	49.6
Magnesium (Mg)......	23.9	25.12
Sodium and potassium (Na+K)......	4.6	1.6
Carbonate radicle (CO_3)......	99.6	123.7
Sulphate radicle (SO_4)......	6.6	18.8
Chlorine (Cl)......	15.7	3.0
Nitrate radicle (NO_3)......	19.5	......
Total dissolved solids......	211.	222.

1. City Water Supply, Westby, Analyst, G. N. Prentiss, April 10,1912.
2. Railroad well at La Farge, Analyst, G. N. Prentiss, Feb. 4, 1908.

VILAS COUNTY

Vilas County, located in the northern part of the state, has an area of 907 square miles, and a population of 6,019. Only 3.6 per cent of this county is laid out in farms, of which only 23.9 per cent is under cultivation.

SURFACE FEATURES

The county is nearly a level plain, dotted with numerous lakes at the head waters of the Wisconsin river. The altitude is mainly between 1,600 and 1,700 feet. The soil is generally a sandy soil or sandy to silty loam. Probably not more than 30 or 40 per cent of this county will eventually be brought under cultivation. It is a region well adapted to summer resorts, fishing and hunting.

GEOLOGICAL FORMATIONS

The geological formation is principally the surface formation of glacial drift, associated with plains of sand and gravel of alluvial or glacio-alluvial origin. Underlying the surface formation are the granite and associated crystalline rocks. The surface deposits quite effectually cover the hard rock throughout the county, and usually vary in depth from 50 to 200 feet.

PRINCIPAL WATER-BEARING HORIZONS

The principal water-bearing formations are the surface deposits of drift, sand and gravel, which very generally yield an abundant supply of water at shallow depth. The water level is very generally near the surface, and wells are usually only 15 to 40 feet deep. Caution should be observed in the use of shallow water supplies. The best practice is to use drilled or driven wells, properly cased to a depth of at least 20 or 30 feet below the general water level.

WATER SUPPLIES FOR CITIES AND VILLAGES

Eagle River. Eagle River, the county seat, has an estimated population of 1,200. It is located on the site of water power on Eagle River. Its elevation is 1,142 feet above sea level. The city has a water supply mainly for fire service, the supply being taken from a large open well, 12 feet deep and 30 feet in diameter, located on the bank of the river. About 40 per cent of the houses connect with the water supply system. The average depth of the private wells is about 20 feet in sand and hard pan.

Arbor Vitae. Arbor Vitae, located on Arbor Vitae lake, has a population of about 1,250. Its altitude is 1,630 feet. No city water or sewage system is installed. Wells are from 15 to 40 feet deep in a sandy gravel formation.

QUALITY OF WATER SUPPLIES

The analyses of water supplies from lakes, creeks, and surface deposits, shows a remarkably low content of mineral matter, the average mineralization of the 5 waters analyzed being appreciably less than that of Lake Superior water. Very soft, or soft water is very probably characteristic for the entire county, though occasionally hard waters may be found as in Oneida county.

The water of the lake at Woodruff contains only 0.11 pounds of incrusting solids in 1,000 gallons, while the city water supply at Eagle contains 0.43 pounds of incrusting solids in 1,000 gallons.

Mineral Analyses of Water in Vilas County.

(Analyses in parts per million)

	Lakes.				
	1.	2.	3.	4.	5.
Silica (SiO_2)	1.1	16.5	13.	5.	4.1
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	0.7	6.2	1.1	5.	trace
Calcium (Ca)	0.7	7.2	6.7	0.6	2.4
Magnesium (Mg)	0.3	2.8	2.5	1.2	.6
Sodium (Na)	und't.	2.6	0.8	0.3	1.2
Potassium (K)	und't.	1.7	0.3	0.6	
Carbonate radicle (CO_3)	5.4	15.2	11.	1 7	3.3
Sulphate radicle (SO_4)	5.3	7.9	6.4	1.4	2.9
Chlorine (Cl)	4 5	2.7	3.	2.5	1.8
Organic matter	....	....	....	....	10.0
Total solids	18.	63.	45.	18.	16.

	Creek.	Surface deposits.		
	6.	7.	8.	9.
Depth of well........feet	....	12	36	60
Silica (SiO_2)	1.7	4.6	12.5	8.5
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)	4.8	2.7	.7	
Calcium (Ca)	9.8	11 4	8.2	7.0
Magnesium (Mg)	3.3	4.3	1.5	1.6
Sodium (Na)	3.2	2.0	3.7	2.7
Potassium (K)				
Carbonate radicle (CO_3)	22.9	26.9	13.5	3.9
Sulphate radicle (SO_4)	4.4	1.4	9.1	21.4
Chlorine (Cl)	1.6	3.1	4.1	0 8
Organic matter	....	10.2	....	....
Total solids	52.	56.	53.	46.

1. Clear Lake, near Minocqua. Sample from surface. Analysts, E. B. Hall, and C. Juday, Sept. 1907. Wis. Survey Bull. 22, p. 170.
2. Lake Kewaugesaga, near Minocqua. Analysts, E. B. Hall and C. Juday, Aug. 26, 1907. Wis. Survey Bull. 22, p. 170.
3. Trout Lake, south part, sample analyzed from surface, Analysts, E. B. Hall and C. Juday, Aug. 19, 1907. Wis. Survey Bull. 22, p. 170.
4. Bass Lake, sample from surface, Analysts, E. B. Hall and C. Juday, Sept. 1907. Wis. Survey Bull. 22, p. 170.
5. Lake at Woodruff, Analyst, G. M. Davidson, C. & N. W. Ry. Co., Dec. 23, 1904.
6. Creek at Fosterville, Analyst, G. M. Davidson, C. & N. W. Ry. Co., Sept. 29, 1909.
7. City Supply at Eagle River well 30 ft. diameter, 12 ft. deep, on bank of Eagle river, Analyst, G. M. Davidson, Aug. 1909.
8. Railroad well at Lac du Flambeau, Analyst, G. M. Davidson, C. & N. W. Ry. Co., May 29, 1909.
9. Railroad well at Alva, Analyst, Chemist C. M. & St. P. Ry. Co., May 11, 1895.

WALWORTH COUNTY

Walworth county, located in the southeastern part of the state, has an area of 562 square miles and a population of 29,614. About 94 per cent of the county is in farms, of which 72.2 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is a gently undulating plain with broad valley bottoms and gently sloping hills. Broad marshes along the streams are a characteristic feature. Lakes are common, the most important and best known being Lake Geneva, Delavan Lake, Lauderdale Lakes, and Lake Beulah. The county is drained by streams flowing westward to Rock river, the Turtle Creek and Whitewater Creek, and streams flowing eastward to the Fox river (of Illinois), the White river and Honey Creek. Belts of terminal moraine, the Kettle Range, cover a considerable part of the county.

The elevation of Lake Geneva is 862 feet above the sea, 282 feet above Lake Michigan. The elevation of Delavan Lake is about 920; of Lake Beulah about 810, and of the Lauderdale Lakes about 882 feet above sea level. These lakes are from 50 to 65 feet deep.

The lowest land in the western part of the county at Whitewater is about 829 feet, and along Turtle Creek at Fairchild about 880 feet, while the lowest land in the eastern part, along the White river near Burlington, is about 760 feet above sea level. The highest uplands reach an altitude of a little over 1,000 feet, a much larger proportion of the land of the western part reaching this altitude than of the eastern part. The maximum range in altitude between the highest hills and the adjacent valleys is less than 200 feet.

GEOLOGICAL FORMATIONS

The geological strata outcropping at the surface or immediately underlying the glacial drift are the Galena-Platteville (Trenton) limestone, the Cincinnati shale and the Niagara limestone. The Galena and Cincinnati area of outcrop is only in the western part of the county and that of the overlying Niagara in the central and eastern part. The section, Fig. 44, illustrates the geological structure of Walworth, Racine and Kenosha counties.

Glacial drift and alluvial deposits of variable thickness, up to over 300 feet, fill the pre-glacial valleys, and in thinner deposits, usually less than 100 feet thick, overlie the slopes and summits of the hills. Two belts of terminal moraine, the Darien and Elkhorn moraines, consisting of hummocky drift hills and associated depressions extend across the county in a crescent-shaped zone through the vicinities of Lake Geneva, Delavan, Richmond, and La Grange Centre.

The thickness of the Niagara limestone, Cincinnati shale, and Galena-Platteville (Trenton) limestone varies on account of erosion where-ever these formations outcrop at the surface or underlie the drift. The formations underlying the Trenton vary in thickness only to a slight extent, due to inequalities in the original deposition. The approximate range in thickness of the geological formations in the county may be summarized as follows:

Approximate range in thickness of formations in Walworth County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Niagara limestone	0 to 350
Cincinnati shale	0 to 225
Trenton limestone	50 to 250
St. Peter and Lower Magnesian	150 to 250
Upper Cambrian (Potsdam) sandstone	800 to 1,000
The Pre-Cambrian	....

PRINCIPAL WATER-BEARING FORMATIONS

All of the geological formations are drawn upon for water supplies, but the most common source is the drift overlying the rock formations. Wherever the Galena-Platteville limestone and Niagara limestone are near the surface, abundant supplies are drawn from them. The water level in the drift is generally near the surface except on the summits of the isolated ridges. The depth of wells in the drift, however, is quite variable as illustrated in Elkhorn, where on a very gently sloping area, the wells range from 10 to 150 feet deep.

The Cincinnati shale lying between the Niagara and the Galena-Platteville limestone forms an impervious basement for groundwater in the overlying Niagara limestone and glacial drift.

FLOWING WELLS

While the water in the sandstone underlying the Galena-Platteville limestone is held under hydrostatic pressure, the land surface is generally too high for the development of flowing wells from the sandstone. It is only on the lowest ground of the county, therefore, that artesian flows are obtainable from the underlying rock strata.

At Whitewater the city is supplied from flowing wells, altitude of curb 820 feet, with 19-foot head, the source of the flow being in the Galena-Platteville limestone and the St. Peter and Upper Cambrian (Potsdam) sandstones, the pressure increasing with depth. In the valley of White river at Burlington flowing wells are obtained with a 30-foot head, the altitude of the curb being 765 feet. Flows from deep seated strata can probably be obtained up the White river valley where the altitude of the surface does not exceed 800 feet. At Lake Geneva the artesian head is at 790 feet, 59 feet below the surface, and at East Troy 820 feet, 40 feet below the surface.

Flowing wells from the surface deposits of drift or within the Niagara limestone occur at much higher altitudes, depending upon local conditions. Flowing wells of this type occur southeast of Elkhorn, and between Elkhorn and Eagle, and in other parts of the county.

SPRINGS

Springs are an important source of water supply on low ground adjacent to the terminal moraines, and especially where the drift overlies the shale. Springs are especially abundant at the horizon of the outcrop area of the Cincinnati shale which forms a belt two to six miles wide across the western part of the county. Numerous springs occur in the vicinity of Whitewater, within the area of artesian flowing wells. The city supply of Delavan is obtained from springs, and a well known mineral spring, the Sheridan Mineral Spring, is located near Lake Geneva.

WATER SUPPLIES FOR CITIES AND VILLAGES

Lake Geneva. This city located at the east end of Lake Geneva, has a population of 3,079. The city has a water supply but no sewage system. The water supply is obtained from three wells and a reservoir well fed from an intake leading from a spring. For a number of years, the water was obtained from a large open reservoir well, 30 feet in diameter and 30 feet deep, but this source was unsatisfactory. Two of

the earlier city wells were 186 and 210 feet deep in red clay and gravel at bottom. Recently the city supply was increased by adding a deep well 12 inches in diameter and 1,119 feet deep. The estimated daily capacity is over 1,000,000 gallons. The new well is supplied with a compound centrifugal pump. About 50 per cent of the houses are connected with the city water supply. Most of the private wells are about 35 feet deep, and vary between 20 and 150 feet. The detailed section of the deep city well is as follows:

Log of Lake Geneva City Well.

Formation.	Thickness.	
Drift:	Feet.	
Gravel and water	20	
Clay	15	
Gravel and a little water	5	
Hard pan	55	
Clay mixed with stone	85	
Gravel and a little water	20	
Clear gravel, good water supply	23	223
Cincinnati:		
Blue shale	34	
Limestone with streaks of shale	15	
Blue shale	76	125
Galena-Trenton:		
Limestone	83	
Blue shale	63	
Limestone with streaks of shale	92	
Blue rock	10	248
St. Peter:		
Variegated colored rock of all sorts	106	106
Lower Magnesian:		
Blue hard stone	5	
Sandy shale	95	
Rock	55	
Shale	20	
Honeycombed rock with flint moulds, and sand in the pockets. This source of main supply at top of Potsdam	17	192
Upper Cambrian (Potsdam):		
Rock with streaks of shale	19	
Red sandstone	35	
White sandstone	57	
Red sandstone	39	
Red rock and shale	14	
Shale	54	
Sandstone	7	225
Total depth	1,119	1,119

The log of a well three miles southwest of Lake Geneva owner, M. W. Ryenson, driller, M and L. E. Trow as determined from samples by F. T. Thwaites, is as follows:

Log of well of M. W. Ryenson, near Lake Geneva.

Formation.	Depth.	Thickness.
Pleistocene:	Feet.	Feet.
Brownish red clay	1— 5	
Gray fine sand	5— 23	
Light reddish clay	23— 35	
Brownish gray clay	35— 70	
Sand and gravel	70— 80	
Sandy clay, brownish	80—115	
Sand and gravel	115—160	
Same as at 80-115	160—185	
No sample. Sand	185—195	
Same as at 80-115	195—230	
Sand and gravel	230—240	
Dark clay, no sample	240—244	244
Niagara Limestone:		
White cherty limestone, much broken	244—285	
Light brown limestone	285—305	
Same as above	305—315	76
Cincinnati Shale:		
Greenish gray soft shale	320—322	
Gray and red shale	322—335	
Hard white limestone	335—343	23
Total depth		343

Elkhorn. This city, the county seat, has a population of 1,707. The city water supply is obtained from a 10-inch artesian well, 1,040 feet deep. The elevation of the curb is about 1,010 feet above sea level, and the water stands 145 to 160 feet below the surface. The water is pumped by an air lift system. The estimated daily capacity is 150,000 gallons, and the average daily pumpage is 140,000 gallons. About 60 per cent of the houses are connected with the city supply. A sewage system was recently installed. The sewage is purified by residential septic tanks and emptied into the marsh. The section of the city well is as follows:

Log of Elkhorn City Well.

Formation	Thickness.
Drift	Feet.
Clay and gravel	213
Cincinnati	
Soft slate shale	119
Shale and limestone	48
Galena-Trenton	
Limestone	185
Blue limestone	50
Buff limestone and sandstone	35
St. Peter	
Sandstone	50
Lower Magnesian	
Limestone and sandstone	50
Hard limestone	19
Upper Cambrian (Potsdam)	
Soft sandstone (drill dropped 3 feet in cavity)	146
Pink and cream sandstone	100
Brown sandstone	25
Total depth	1040

Flowing wells are obtained between Elkhorn and Eagle from both Niagara limestone and glacial drift. Similar conditions prevail southeast of Elkhorn. In Elkhorn, private wells vary from 10 to 150 feet in depth.

Whitewater. The population of Whitewater is 3,224. The city has a water supply, and a sewage system. The water supply is obtained from 4 artesian wells from 250 to 957 feet deep. The first two artesian wells were drilled 957 and 565 feet deep. The first well, 957 feet deep, 6 inches in diameter flowed 19 feet above the surface. The first flow was obtained in the Trenton limestone at 142 feet, the second in the St. Peter sandstone at 175 feet. The flow continued to increase to the bottom of the Potsdam. When completed, the well flowed 115 gallons per minute and varied with the pressure of the atmosphere from 104.6 to 115.9 gallons per minute.

The second well, 10 inches in diameter and 565 feet deep, flowed 275 gallons per minute at the surface. The water is stored in an uncovered reservoir having a capacity of 885,000 gallons. The average daily pumpage is about 162,000 gallons. About 50 per cent of the houses are connected with the city supply. The log of the 957 foot well is as follows:

Log of Whitewater City Well.

Formation.	Thickness.
	Feet.
Pleistocene.	
Blue clay	15
Galena-Trenton.	
Blue limestone	37
Buff limestone	96
St. Peter, Lower Magnesian and Potsdam.	
Sandstone	85
Limestone	7
Sandstone	9
Limestone	4
Sand	9
Blue shale	31
Sandstone	57
Silicious sandstone	6
Fine sandstone	109
Red sandstone	53
Blue shale	24
Silicious sandstone (strong flow)	79
Fine sandstone	231
Red marl	38
Red marl and sand	25
Coarse silicious sand	42
Total	957

Delavan. The population of Delavan is 2,450. The city water supply is obtained from two 110 and 125-foot wells. The sewage, without purification empties into Turtle Creek. About 60 per cent of the houses are on the water system and 50 per cent on the sewage system. An ar-

tesian supply of water could readily be obtained by drilling a 10 or 12-inch well 800 to 1,000 feet deep and obtaining a supply from the Potsdam sandstone.

East Troy. The village of East Troy has a population of 673. The village has a public water supply system, obtained from one well about 700 feet deep, and 8 and 6 inches in diameter. The capacity of the reservoir tank is 30,000 gallons. About 60 houses at present are connected with the system. The depths of private wells in the village are generally 30 to 40 feet. About a mile east of the village of East Troy is an interesting well 2,200 feet deep, owned by Stephen A. Field. The elevation of the curb is 860 feet, and the water stands 40 feet below the surface. The record of this well is as follows:

Log of S. A. Field's Well, East Troy.

Formation.	Thickness.
Pleistocene.	Feet.
1 Drift	330
Galena-Trenton.	
2 White limestone	80
3 Blue Limestone	50
4 Grey cherty limestone	116
St. Peter.	
5 White sandstone	104
6 Brown sandstone	16
Lower Magnesian and Potsdam-	
7 Blue shale	3
8 Buff limestone	21
9 White limestone0	20
10 Hard gray limestone	20
11 Red limestone	50
12 White sandstone	30
13 Brewn yellow sandstone	10
14 Fine sandstone	40
15 Flesh red sandstone	20
16 Brown limestone and sandstone	10
17 Red marl	20
18 Brown limestone and sandstone	40
19 Red marl	15
20 Red and brown sandstone	20
21 White, slightly red sandstone	5
22 White sandstone	45
23 Buff sandstone	5
24 White sandstone	10
25 White and brown sandstone	10
26 Coarse buff sandstone	60
27 Flesh tinted sandstone	40
28 Red marly sandstone	35
29 Flesh tinted sandstone	25
30 Fine white sandstone	30
31 Buff sandstone (coarse)	20
32 Blue slate sandstone	10
33 Brown sandstone	65
34 Gray white sandstone	110
35 Buff sandstone	15
36 Pink sandstone	75
37 Fine pink sandstone	35
38 Buff sandstone	4
39 Pink sandstone	11
40 Light buff sandstone	20
41 Pink sandstone	55
42 Coarse buff sandstone	15
43 Limestone sandstone	10
44 Ferruginous sandstone to bottom, no samples	435
Total depth	2,200

In the above log of the S. A. Field well, the Lower Magnesian (Shakopee and Oneota) may extend down as far as bed 19 or 20, indicating a thickness of about 300 feet. The Upper Cambrian (Potsdam), including the Madison and Mendota beds, may comprise the remainder of the section, indicating a thickness of about 1,200 feet, which is unusual for this part of the state, though a similar thickness of the Upper Cambrian appears to be developed farther south in northern Illinois. It is possible also that bed 44 may be in part Pre-Cambrian formation.

Walworth. Walworth, a village of 755 population, has no public water supply or sewage system. The depths of private wells are reported to be from 70 to 80 feet, the first 8 feet in clay and loam, and the remainder in sand and gravel.

Sharon. Sharon, with a population of 879, has a public water supply obtained from a flowing well, 8 inches in diameter and 610 feet deep. The average daily pumpage at present is 21,000 gallons. About 80 per cent of the houses are connected with the supply.

QUALITY OF THE WATER

The mineral analyses of waters from various springs, creeks, lakes, and wells of Walworth county are shown in the following table. The waters of lowest mineral content are from the surface supplies of Nippersink Creek and Lake Geneva. The water of the lake shows a lower content of lime than of magnesia, very probably due to the abstraction of lime by lime-secreting organisms living in the lake.

The spring waters are all very hard carbonate waters. The analysis of the water of the Richmond spring at Whitewater, No. 9 made many years ago, seems to indicate, by the high content of the chlorine and organic matter, that the spring was polluted by contaminated surface water.

The analyses of well waters from the surface deposits and the sandstone underlying the limestones of the county are much the same in character and content of mineral matter. All are either hard or very hard waters of moderate mineral content. The water supplies obtained from the Cincinnati shale, or from formations closely associated with it, are likely to be more highly mineralized than those shown in the table.

The water from Lake Geneva, No. 2, contains 1.54 pounds of incrusting solids in 1,000 gallons, while that from the railroad well at Lake Geneva, No. 11, contains 2.46 pounds in 1,000 gallons.

Mineral analyses of water in Walworth County.

(Analyses in parts per million)

	Creeks.	Lakes.			Springs.				
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Silica (SiO_2) / Aluminium and iron oxides ($Al_2O_3 + Fe_2O_3$)	13.3 / 2.0	3.6 / 0.5	9.5 / 1.1	1.5	13.	24.	12.5	15.8	20.
Aluminium oxide (Al_2O_3)	......	......	....	....	2.	......	0.8	0.7	trace.
Iron (Fe)	......	......	....	....	2.5	......	0.9	0.5	3.8
Calcium (Ca)	61.7	29.6	20.7	39.3	70.4	84.8	93.	113.6	114.
Magnesium (Mg)	26.7	30.0	26.9	36.2	35.1	40.	50.	62.3	54.5
Sodium (Na) / Potassium (K)	7.5	8.5	4.3 / 2.5	14.8	8.4	9.	3.8	25.2	17.6
Carbonate radicle (CO_3)	153.4	115.0	92.3	160.0	193.4	225.2	255.	345.6	323.6
Sulphate radicle (SO_4)	32.4	11.4	13.2	7.5	11.8	12.8	20.8	7.7	2.7
Chlorine (Cl)	3.2	8.8	4.2	2.4	4.8	4.2	3.2	6.5	29.5
Organic matter	4.2	......	....	....	......	......	4.	......	43.
Total dissolved solids	300.	207.	175.	262.	341.	400.	440.	578.	565.

1. Nippersink Creek, Genoa Junction, Analyst, G. M. Davidson, May 9, 1901.
2. Lake Geneva, Williams Bay, Analyst, G. M. Davidson, July 9, 1909.
2. Lake Geneva, mean of four analyses at various depths, Analyst, E. B. Hall and C. Juday, Sept. 26, 1907, Wis. Sur. Bull. 22, p. 170.
4. Cravath Lake, Whitewater, Analyst, Chemist, C. M. & St. P., Sept. 20, 1889.
5. Gihon Spring, Delavan, Analyst, G. Bode, Geoloyy of Wis. Vol. 2, p. 146, 1877.
6. East Troy Spring, East Troy, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 31, 1877.
7. Sheridan Spring, Lake Geneva, Anayst, G. Bode.
8. Sheridan Spring, Lake Geneva, Analyst, E. G. Smith.
9. Richmond Spring, Whitewater, Analyst, J. E. Garner, 1873, Geol. of Wis. Vol. 2, p. 31.

Mineral analyses of water in Walworth County—Continued.

	Surface deposits.								
	10.	11.	12.	13.	14.	15.	16.	17.	18.
Depth of well........feet	35.	8.	62.	75.	68.	70.	93.	144.	156.
Silica (SiO_2)	......	14.9	26.2	......	Undt...	......	....	....	....
Aluminium and iron oxides ($Al_2O_3 + Fe_2O_3$)	6.7	2.9	13.3	8.7	....	0.9	Undt...	12.4	Undt.
Calcium (Ca)	52.9	62.1	65.6	81.9	62.4	69.0	67.9	81.3	75.6
Magnesium (Mg)	25.9	32.8	34.6	28.2	33.0	34.7	33.3	42.6	41.0
Sodium and potassium (Na + K)	9.7	19.4	0.2	8.3	9.3	2.3	1.9	15.1	23.1
Carbonate radicle (CO_3)	112.6	158.8	159.9	187.3	159.7	176.4	174.8	210.6	212.8
Sulphate radicle (SO_4)	66.0	43.0	38.2	20.8	43.2	19.2	14.9	50.8	38.7
Chlorine (Cl)	1.3	16.1	0.3	3.1	Undt...	3.6	2.1	4.9	9.4
Organic matter	......	......	7.3	......	....	......	....	....	....
Total dissolved solids	275.	350.	345.	338.	308.	306.	295.	418.	401.

10. Well of C. M. & St. P. Ry. Co., Allens Grove, Analyst, Chemist, C. M. & St. P. Ry. April 11, 1891.
11. Well of C. & N. W. Ry. Co., Lake Geneva, Analyst, G. M. Davidson, Sept. 1891.
12. Flowing well of Godfrey Price, Genoa Junction, Analyst, G. M. Davidson, June 11, 1908.
13. Well of C. M. & St. P. Ry. Co., Troy Center, Analyst, Chemist, C. M. & St. P. Ry. April 10, 1891.
14. Well of Chicago & L. G. Ry. Co., Walworth, Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 27, 1900.
15. Well of Chicago & L. G. Ry. Co., Walworth, Analyst, Chemist, C. M. & St. P. Ry. Co., Oct. 4, 1901.
16. Well of C. M. & St. P. Ry. Co., Walworth, Analyst, Chemist, C. M. & St. P. Ry. Co., July 20, 1901.
17. Well of C. M. & St. P. Ry. Co., Elkhorn, Analyst, Chemist, C. M. & St. P. Ry. Co.; Mar. 27, 1891.
18. Well of C. M. & St. P. Ry. Co., Elkhorn, Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 26, 1910.

Mineral analyses of water in Walworth County—Continued.

	St. Peter sandstone.			Upper Cambrian (Potsdam) sandstone.			
	19.	20.	21.	22.	23.	24.	25.
Depth of well.................feet	200.	315.	764.	990.	957.	1,100.	....
Silica (SiO_2)......................	....	10.0	13.1	1.3	7.8	....	....
Aluminium and iron oxides ($Al_2O_3 + Fe_2O_3$)................	Undt...	....	....	....	....	0.9	Undt...
Aluminium oxide (Al_2O_3)........	....	....	....	....	1.3	....	....
Iron (Fe)..........................	....	1.5	....	....	0.3	....	....
Calcium (Ca)........................	79.4	67.3	70.3	67.0	65.4	66.5	57.4
Magnesium (Mg)....................	36.4	33.9	35.6	35.9	39.9	36.3	30.7
Sodium (Na)..........................	7.8	6.9	28.5	10.5	3.4	6.5	41.6
Potassium (K).......................		0.9					
Carbonate radicle (CO_3)..........	210.6	193.5	231.4	184.1	194.	182.5	209.9
Sulphate radicle (SO_4)............	7.2	3.0	Trace	8.3	7.7	9.6	Trace..
Chlorine (Cl)........................	4.1	1.1	Trace	16.2	10.5	10.0	6.2
Phosphate radicle (PO_4)..........	....	....	....	....	Trace..	....	....
Organic matter.......................	....	....	69.7	....	....	....	....
Total solids....................	345.	318.	379.	323.	330.	312.	346.

19. Well of Wehyer Wagon Works, Whitewater, Analyst, G. N. Prentiss, Dec. 23, 1909.
20. Well of Mr. Blackman, Whitewater, Analyst, E. G. Smith.
21. Well of Yerke's bservatory, Williams Bay.
22. Private well, Whitewater, Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 12, 1889.
23. Well of City Water Supply, Whitewater, Analyst, W. W. Daniells.
24. Well of City Water Supply, Whitewater, Analyst, Chemist, C. M. & St. P. Ry. Nov. 11, 1896.
25. City well Elkhorn, Analyst, G. N. Prentiss, Jan. 26, 1910.

WASHBURN COUNTY

Washburn county; located in the northern part of the state, has an area of 834 square miles, and a population of 8,196. About 27.2 per cent of the land is laid out in farms, of which 28.6 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is gently rolling, and is characterized by belts of drift hills and areas occupied by numerous lakes. The soils vary from silt loams to sandy gravelly soils. The principal rivers are the Totogatic, Nemakagon and Yellow, flowing westward to the St. Croix. Important lakes of the county are Spooner Lake, Shell Lake, Long Lake, Gilmore Lake and Pokegama Lake. The depths of some of the lakes are as follows: Pokegama, 22 feet; Gilmore, 33 feet; Shell Lake, 80 feet; Long Lake, 78 feet.

The highest portion of the county is in the southern part, in the vicinity of Shell Lake, Sarona, and farther east, where the general al-

titude is between 1,200 and 1,400 feet above sea level. Farther north, in the broad valleys of the Yellow, Nemakagon and Totogatic, the general altitude is between 1,000 and 1,200 feet.

GEOLOGICAL FORMATIONS

The glacial drift, and alluvial sand and gravel are the principal formations appearing at the surface. Only a few outcrops of crystalline rock appear along the river bottoms. The surface formation is usually very thick throughout the county. Many wells are from 50 to 100 feet deep without striking rock. In the southern part of the county the drift is usually from 100 to 200 feet thick. At Spooner the gravel and sand is at least 217 feet thick. The section, Fig. 23 illustrates the geological structure of Washburn and adjacent counties.

WATER-BEARING HORIZONS

The principal water-bearing formation is the thick mantle of surface formation overlying the crystalline rock. This formation consists of abundant deposits of sand and gravel containing large supplies of good water. It is quite likely that there are beds of sandstone, in a few places, underlying the surface deposits and in such cases the sandstone will furnish an additional supply.

Abundant water is generally found at depths of 20 to 50 feet. In the valley bottoms the water level is near the surface. On the broad uplands about Sarona, Shell Lake, and Barronett there are many farm wells from 75 to 125 feet deep in the drift.

WATER SUPPLIES FOR CITIES AND VILLAGES

Spooner. Spooner has a population of 1,453. It is located upon a nearly level, relatively sandy tract, bordering Yellow river, the outlet of Spooner Lake. Its elevation is 1,094 feet above sea level. A public water supply was recently installed, but no general sewage system has been put in. The supply is obtained from the river, and a 217-ft. well, with 12 inch casing to bottom. Elevation of the curb is about the same as at station, 1,094 feet. The formation is mostly fine sand and gravel, with a gravel bed at the bottom. Estimated capacity of well is 300,000 gallons per day, and the daily pumpage is about 460,000 gallons. About 75 per cent of the houses are reported to connect with the city water supply. The sandy,gravelly formation, upon which the city is located,

furnishes an abundant supply of water at relatively shallow depths. The private wells are generally from 20 to 50 feet deep.

The log of the Spooner City well showing the character of the sand and gravel formation, as determined by samples in possession of the University, is as follows:

Log of Spooner City Well.

Formation.	Depth.
	Feet.
Sand no sample	....
Medium brown sand	20-40
Same, coarser and lighter	40-60
Sand and gravel, pebbles of quartzite, trap and granite	60-80
Sandy calcareous clay	80-100
Sand and gravel, pebbles of quartzite, sandstone trap and granite	100-140
Same but finer	140-160
Same, finer red sand	160-180
Pink quartz sand	180-200
Coarse dark red sand and fine gravel, quartz (and diorite) pebbles	200-215
Coarse pink quartz sand	215-217
Total depth	217

Shell Lake. Shell Lake has a population of 902. It is located on Shell Lake, a body of water 4 to 5 square miles in extent. Its elevation is 1,241 feet above sea level. Water works, for fire protection and domestic services only, obtains its supply from the lake through an 8 inch intake 275 feet in length. The average daily pumpage is about 46,000 gallons. About 80 per cent of the population use the city supply. No sewage system is installed. The city is located upon an undulating shore reaching from 40 to 80 feet above the lake. The formation is a sandy loam soil with sandy, gravelly subsoil. The private wells are from 20 to 60 feet deep.

QUALITY OF THE WATER

The water of Washburn county from ground water as well as surface sources is likely to be soft water throughout, essentially similar to that at Spooner, as indicated by the following analysis. The city water at Spooner contains 0.88 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Washburn County.

(Analyses in parts per million)

	Surface deposits.
	1.
Depth of well....feet....	217
Silica (SiO_2)	16.8
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	1.5
Calcium (Ca)	24.5
Magnesium (Mg)	7.2
Sodium and potassium (Na+K)	1.8
Carbonate radicle (CO_3)	43.8
Sulphate radicle (SO_4)	1.2
Chlorine (Cl)	2.9
Total dissolved solids	99

1. City water supply at Spooner. Analyst, G. M. Davidson, C. & N. W. Ry. Co., July 1, 1902.

Washington County

Washington county, located in the southeastern part of the state, has an area of 423 square miles and a population of 23,784. About 95.3 per cent of the county is in farms of which 66.1 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is an undulating plain sloping southeastward, being more undulating and hilly in the western part than in the eastern part. The cenrtal and eastern parts are drained by the Cedar river flowing south and east to join the Milwaukee, a tributary of Lake Michigan. The western part of the county is drained by the headwaters of the Rock river, flowing westward. Pike lake and Cedar lake, and a prominent belt of drift hills, the Kettle Range, are located in the western part.

The valley bottoms of the eastern part of the county reach altitudes a little above 800 feet, about 200 feet above Lake Michigan, while those in the western part are between 900 and 1,000 feet. The upland ridges in the eastern part rarely exceed an altitude of 1,000 feet, while those in the western part generally reach 1,100 to 1,200 feet and in a few

places over 1,300 feet. The high drift hills of the Kettle Range southeast of Hartford in several places exceed 1,300 feet, the highest point, Holy Hill, reaching an altitude of 1,361 feet, about 360 feet above the valley bottom at the foot of the hill. Holy Hill is the highest point in southeastern Wisconsin, east of the Rock river valley. The range in the elevation in the eastern part is generally less than 150 feet, while the range in elevation in the western part is often 200 to 250 feet, and in a few places 300 to 350 feet.

GEOLOGICAL FORMATIONS

The geological formations of the county are the Niagara limestone and the overlying surface deposits of glacial drift. It is only along the Rubicon river west of Hartford that the Cincinnati shale is present.

The drift is of variable thickness ranging from zero up to 150 or 200 feet. There are many places in this county where the drift is either not present or it lies in very thin deposits. The belt of irregular drift hills associated with small marshes, lakes and depressions, the Kettle Range trends northeastward across the western part of the county through the vicinity of Schleisingerville, West Bend and Kewaskum.

The Niagara limestone is also of variable thickness on account of its general erosion before the drift was deposited upon it. The known maximum thickness of the Niagara is only 250 feet at West Bend but it is very probable that this formation may attain a thickness of 400 to 450 feet in many places in the county.

The thickness of the Cincinnati shale at West Bend is reported to be 200 feet. While this is probably the usual thickness it may slightly exceed this in some places.

At Hartford a well was drilled in 1900 to a depth of 890 feet striking hard quartzite rock at depth of only 541 feet. A well recently drilled by the railroad at Rugby Jct., struck hard rock at depth of 840 feet. Ordinarily the depth to the granite floor in this locality would be about 1,300 or 1,400 feet. The unusual nearness of the Pre-Cambrian at the above places is probably due to the fact that there are buried mounds of quartzite at these places, similar to the partially buried mounds and knobs of granite and quartzite that protrude up through the sandstone and limestone formations farther west in the Fox river valley. The usual range in thickness of the formations in Washington county may be summarized as follows:

Probable range in thickness of formations in Washington County.

Formation.	Thickness.
	Feet.
Surface deposits	0 to 250
Niagara limestone (partly eroded)	200 to 450
Cincinnati shale	180 to 220
Galena-Platteville (Trenton) limestone	200 to 250
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	600 to 800
Pre-Cambrian granite	

PRINCIPAL WATER-BEARING HORIZONS

All the geological formations are drawn upon for water supplies, but the usual sources are the surface deposits of glacial drift and the underlying Niagara limestone. It is only in a few deep wells that the formations underlying the Niagara limestone are drawn upon. In the valley bottoms southwest of Hartford, the source of supply is in the shale or the overlying drift.

The drift wells obtain their supply from porous beds of sand and gravel in the drift at depths usually varying from a few feet up to 100 feet. Relatively shallow wells from 10 to 40 feet were formerly very common in the drift but the supply in the shallow wells is often inadequate and many of the drift wells have been deepened and obtain their supply from the underlying rock, or at the contact of the rock and the drift.

The Niagara limestone formation contains numerous water bearing fissures and wells are very common at depths varying from a few feet up to 100 feet. The drilled wells in limestone are more expensive than the shallow drift wells, but the water is usually of better quality and the supply larger and more constant.

FLOWING WELLS

Flowing wells having their source in the drift and in the Niagara limestone are common on low ground adjacent to the Milwaukee and Menomonee rivers and tributaries in the southeastern part of the county.

In the city of West Bend and vicinity in Sections 14, 23 and 24, are numerous flowing wells from 15 to 150 feet deep, the source of the supply being in gravel underlying relatively impervious glacial clays. These flowing wells depend on local conditions and flow under variable

pressure, the original head when first drilled being from 1 to 20 feet above the surface.

In West Bend and also south of West Bend, the Niagara limestone under the drift yields flowing wells at various places. About Rockfield and South Germantown, over 30 flowing wells have been struck in Niagara limestone within an area 2½ by 5 miles square. (See map Pl. III. and accompanying description of flowing wells, pages 83–4).

While flows are obtained in the drift (See Pl. IV.) and in the Niagara limestone (See Pl. III.) the water from the deeper lying strata such as the Galena-Platteville (Trenton), St. Peter and Upper Cambrian (Potsdam) is not under sufficient pressure to be brought to the surface anywhere in the county on account of the relatively high altitudes. This condition is shown by the deep city well in West Bend, the temporary flow of which was apparently derived from the Niagara formation. The artesian head of the St. Peter and Potsdam water probably does not reach the surface anywhere in Washington county.

SPRINGS

Springs are a quite common source of water supply in various parts of the county. They are quite common at the base of the drift hills of the Kettle Range in the western part, and are also abundant in the southeastern part in the drift and in the underlying limestone. Springs are also abundant along the Rubicon and Oconomowoc rivers within the horizon of the Cincinnati shale formation.

WATER SUPPLIES FOR CITIES AND VILLAGES

West Bend. This city, situated on Milwaukee river, has a population of 2,462. The city has a water supply and sewage system recently installed. The daily pumpage is 75,000 gallons. About 50 per cent of the houses are connected with the supply. The sewage is treated in septic tanks before emptying into the river.

The well for the public supply, 1,206 feet deep, was drilled by the city in 1900, showing the following section:

Section of West Bend City Well.

Formation.	Thickness.
	Feet.
Drift:	
Soil	2
Blue clay	8
Hard pan	50
Gravel	5
Niagara:	
Limestone	250
Cincinnati:	
Shale	200
Sandstone? Trenton, St. Peter, Potsdam	691
Total depth	1,206

Upon completion the water rose to within 4 feet of the surface. After 36 hours pumping the water rapidly dropped 16 feet, or to a depth of 20 feet below the surface. This heavy pumping, however, materially affected the wells at the brewery and other private wells, proving that considerable water was obtained from the Niagara horizon. It stopped the flow for a time of the West Bend Brewery Company's well at the malt house east of the river, but the latter regained its flow shortly after pumping ceased.

Hartford. The population of Hartford, situated on Rubicon river, a branch of the Rock, is 2,982. The city has a water supply obtained from a well 126 feet deep. The sewage is emptied without purification into the mill pond and river. Five hundred and seventy-five houses are connected with the water supply and many have sewer connection. The daily pumpage is about 200,000 gallons.

The well from which the city supply is obtained is reported to be dug 10 feet in diameter for 66 feet, and drilled 60 feet in the drift.

In 1900 a city well was drilled to a depth of about 900 feet, striking hard quartzitic rock, probably Pre-Cambrian quartzite, at about 500 feet. The incomplete record of this well is as follows:

Log of Hartford City Well.

Formation	Thickness.
	Feet.
Drift	6
Niagara limestone	30
Clinton iron ore	4
Cincinnati shale and Galena-Platteville limestone down to 541 feet	507
Quartzite	159
Sandstone, taken for the St. Peter formation	40
Quartzite or very hard rock	159
Total depth	899

F. M. Gray, well driller, states that "white quartz" was struck at 490 feet, and was drilled into for 500 feet without obtaining an adequate supply. Samples of drilling sent to the University, from 541 to 750 feet, are described as "quartzitic rock," varying in color from gray to red. A well drilled at Hartford in 1911 is reported to have struck hard quartzite at 500 feet.

It is apparent, therefore, from the records of several deep wells, that the normal thickness of the water-bearing strata is not obtained at Hartford, because of the occurrence of buried knobs of Pre-Cambrian quartzite or granite similar to those that project above the surface at Baraboo, Waterloo, and in the Fox River valley.

QUALITY OF THE WATER

Analyses of various water supplies from the drift and the Niagara limestone are shown in the following table. Nearly all the waters analyzed are either hard or very hard, calcium carbonate waters. Most of the waters are of moderate mineral content. Six of those analyzed, however, should be classed with waters of high mineral content, and these are characterized by a relatively high content of sulphates.

The waters analyzed in the table may be considered typical for the county. Waters from the Cincinnati shale and the underlying Galena-Platteville (Trenton) limestone are likely to be much higher in mineral content than those obtained from wells of moderate depth in the Niagara limestone or in the surface deposits. Waters from the underlying St. Peter and Potsdam sandstone may be only moderately mineralized or they may be highly mineralized, as illustrated in various localities of eastern Wisconsin.

The water from the Creamery well at Jackson, No. 13, contains only 2.07 pounds of incrusting solids in 1,000 gallons, while that from the railroad well at Rockfield, No. 22, contains 4.53 pounds in 1,000 gallons, and the flowing well at Rockfield, No. 21, contains 9.21 pounds in 1,000 gallons.

Mineral analyses of water in Washington County.

(Analyses in parts per million)

	Mill Pond.		Spring.	Surface deposits (drift).			
	1.	2.	3.	4.	5.	6.	7.
Depth of well..................feet..	....	....	....	14	14	14	35
Silica (SiO_2) .... Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)........	Undt	Undt.	1.7	2.4	Undt.	Undt.	Undt.
Calcium (Ca)........................	98.4	26.5	67.7	83.5	249.5	231.9	122.7
Magnesium (Mg)........................	57.0	13.8	19.5	38.9	94.6	86.6	60.2
Sodium and potassium (Na+K)......	40 0	9.1	1.1	7.6	54.9	37.2	27.1
Carbonate radicle (CO_3)............	299.5	56.9	196.1	179.1	263.6	248.5	200.8
Sulphate radicle (SO_4)	64.4	24.8	5.4	66.4	584.8	572.3	265.6
Chlorine (Cl)........................	Undt.	13.6	1.8	11.6	39.7	Undt.	Undt.
Nitrate radicle (NO_3)................	....	....	....	....	26.4	....	....
Total dissolved solids............	559.	144.	293.	390.	1314.	1177.	676.

	Surface deposits (drift).						Niagara limestone.	
	8.	9.	10.	11.	12.	13.	14.	15.
Depth of well ....feet..	18	20	35	38	14	45	51	84
Silica (SiO_2)........................	......	Undt.	....	4.9	Undt.	20.0	Undt.	Undt.
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	....	....	11.6	....	1.0	....	....
Calcium (Ca)	97.4	65.8	75.5	66.6	78.4	37.8	98.9	78.4
Magnesium (Mg)..................	42.0	43.9	44.3	39.7	43.1	36.8	52.8	43.4
Sodium and potassium (Na+K)..	11.5	9.3	18.6	9.1	5.2	10.5	19.3	Trace.
Carbonate radicle (CO_3).........	204.9	182.7	181.5	172.5	187.7	137.8	181.3	181.2
Sulphate radicle (SO_4)	72.2	30.5	80.3	45.7	68.4	19.0	136.0	49.0
Chlorine (Cl)........................	17.7	14.4	20.7	10.4	....	12.1	43.4	14.0
Organic matter..................	....	....	....	8.2	....	....	....	....
Total dissolved solids........	446.	347.6	421.	361.	388.	275.	532.	366.

1. Mill Pond in Rubicon river, Hartford, Analyst, G. N. Prentiss, Jan. 28, 1902.
2. Mill Pond in River, Hartford, Analyst, G. N. Prentiss, March 19, 1912.
3. Richfield Spring, Richfield, Analyst, Chemist, C. M. & St. P. Ry. Co., July 9, 1889.
4. Well & Pond, Hartford, Analyst, Chemist, C. M. & St. P. Ry. Co., July 10, 1889.
5. Well of C. M. & St. P. Ry. Co., Hartford, Analyst, G. N. Prentiss, Jan. 15, 1902.
6. Well of C. M. & St. P. Ry. Co., Hartford, Analyst, G. N. Prentiss, Jan. 28, 1902.
7. Well at Malt House, Hartford, Analyst, G. N. Prentiss, January 28, 1902.
8. Well "Soo" Ry. Co., Schleischingerville, Analyst, G. N. Prentiss, Feb. 19, 1902.
9. Well of Dow Maxon Creamery, Schleischingerville, Analyst, G. N. Prentiss, Feb. 19, 1902.
10. Well of J. Grimm, Hartford, Analyst, G. N. Prentiss, Jan. 28, 1902.
11. Well of Creamery at Germantown, Analyst, G. N. Prentiss, Feb. 6, 1900.
12. Test well of C. M. & St. P. Ry. Co., Germantown, Analyst, G. N. Prentiss, Jan. 23, 1900.
13. Well of Creamery at Jackson, Analyst, G. M. Davidson, Oct. 15, 1896.
14. Well of Hartford Plow Works, Hartford, Analyst, G. N. Prentiss, Jan. 15, 1902.
15. Well of F. Hill, Hartford, Analyst, G. N. Prentiss, Jan. 15. 1902.

Mineral analyses of water in Washington County—Continued.

	Niagara limestone.						
	16.	17.	18.	19.	20.	21.	22.
Depth of well......feet..	146	202	164	54	58	130	200
Silica (SiO_2)......			....	5.9	7.0	7.5	10.4
Aluminium and iron oxides (Al_2O_3+Fe_2O_3)......	5.4	1.4	....	1.0	1.3	1.0	1.0
Calcium (Ca)......	65.6	64.1	66.1	75.4	75.4	288.5	122.4
Magnesium (Mg)......	16.8	32.3	35.9	49.6	49.2	61.0	49.0
Sodium and potassium (Na+K)......	95.0	13.3	1.7	11.0	16.1	89.0	5.0
Carbonate radicle (CO_3)......	208.4	187.9	184.8	212.8	225.2	311.5	210.1
Sulphate radicle (SO_4)......	85.7	4.4	5.4	36.6	16.1	176.2	156.7
Chlorine (Cl)......	1.6	2.3	2.2	16.9	24.9	5.9	3.9
Total dissolved solids......	479.	306.	296.	409.	415.	936.	559.

16. Well of C. M. & St. P. Ry. Co., Hartford, Analyst, G. N. Prentiss, Oct. 16 1902.
17. Well, owner unknown, Hartford, Analyst, G. N. Prentiss, January 28, 1902.
18. Well of Charles Stark, Schleischingerville, Analyst, G. N. Prentiss, Feb. 19, 1902.
19. Farm well sixty rods from station, Rockfield, Analyst, G. M. Davidson.
20. Farm well eight rods east of Rockfield Station, Analyst, G. M. Davidson.
21. Farm well ¾ mile west of Rockeld station, flowing well, analyst, G. M. Davidson.
22. Artesian well 86 rods north of Rockfield station, flowing well, Analyst, G. M. Davidson, Oct. 1897.

Waukesha County

Waukesha county, located in the southeastern part of the state, has an area of 562 square miles and a population of 37,199. About 93.9 per cent of the county is laid out in farms of which 69.9 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is a gently undulating plain mainly sloping southward. There are only a few points of prominent relief and these are located in the western part. A belt of hummocky drift hills, the Kettle moraine, associated with numerous lakes, lies across the western part of the county. In the eastern part the valleys are broad and the uplands gently sloping. In the western part the topography is more abrupt.

The county is mainly drained by the Fox river (of Illinois) whose headwaters gather in the central part and flow south. The eastern part is drained by streams flowing eastward to Lake Michigan, and the western part by streams flowing west to the Rock river. There are numer-

ous lakes in the county, the principal ones being Muskego lake in the southeastern part, and the large group of lakes in the northwestern part, between Pewaukee and Oconomowoc.

The lowest altitudes in the county are in the southeastern and eastern parts, about 760 feet above sea level along the Fox river and in the vicinity of Muskego Lake, and along the Menominee river below Menominee Falls. The altitudes of the lakes in the northwestern part are as follows:

Altitudes of Lakes in Waukesha County.

	Feet above sea level.
Pewaukee Lake	852
Nagawicka Lake	890
Oconomowoc Lake	862
Okauchee Lake	873
Pine Lake	903
Nehabin Lake	870
Nashotah Lake	871
North Lake	897
Lake Keesus	958

The upland ridges in the eastern part reach altitudes of 950 to 1,050 feet, while the uplands in the western part often reach 1,050 to 1,150 feet. The highest point in the county, Government Hill, reaches an altitude of 1,230 feet, 343 feet above Pewaukee Lake, two miles to the north.

While the range in elevation in the county is nearly 500 feet, the usual difference in elevation between valley bottom and adjacent upland is less than 150 feet and rarely exceeds 250 feet.

GEOLOGICAL FORMATIONS

The Niagara limestone is the bed rock formation in the eastern three-fourths of the county. Along the western border is a belt 5 to 10 miles wide of the Cincinnati shale and the Galena-Platteville (Trenton) limestone. The glacial drift of variable thickness overlying the rock forms a well defined belt of terminal moraine extending north and south in the western part of the county.

The geological structure is illustrated in Fig. 51, p. 451.

The thickness of the Niagara limestone is variable on account of the extensive erosion of this formation. At Waukesha it has a known thickness of 230 feet, but the probable maximum thickness on ridges thinly covered with drift may reach 350 to 400 feet. The total thickness of

the Cincinnati shale is probably 150 to 200 feet, and of the Galena-Platteville (Trenton) limestone 250 to 300 feet. In the western part of the county where these formations outcrop or underlie the drift, the entire formations are not present on account of erosion.

The thickness of the St. Peter sandstone and Lower Magnesian limestone formations combined is about 250 feet, and of the Upper Cambrian (Potsdam) sandstone 800 to 900 feet.

The probable range in thickness of the geological formations in Waukesha county may be summarized as follows:

Probable range in thickness of formations in Waukesha County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Niagara limestone	0 to 400
Cincinnati shale	140 to 200
Galena-Platteville (Trenton) limestone	250 to 350
St. Peter and Lower Magnesian	200 to 250
Upper Cambrian (Potsdam) sandstone	700 to 900
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing horizons are mainly the Niagara limestone and the glacial drift. In the deep wells the underlying sandstone of the St. Peter and the Upper Cambrian (Potsdam) formations are drawn upon.

The water level in the drift is generally less than 100 feet below the surface on the uplands and very near the surface in the valleys. An abundant supply of water can usually be obtained within the porous drift or in the upper surface of the immediately underlying formation of rock.

FLOWING WELLS

Both surface and deep flowing wells occur in Waukesha county. Flowing wells, however, are not abundant, and those that have been developed generally flow at low pressure.

Several flowing wells have been drilled at Pewaukee from 25 to 125 feet deep, the source of the flow being at the contact of the drift with the underlying Niagara limestone. The wells are cased 25 to 35 feet to the limestone and the water rises only 2 to 4 feet above the surface.

There are several shallow flowing wells at Waukesha. A surface flowing well, 114 feet deep, 100 feet in the Niagara limestone, is reported at Waukesha having a flow of 11 feet above the surface. Similar flows occur near Big Bend, at Stone Bank and near Fussville.

It is quite probable that other surface flowing wells occur in various parts of the county on low ground adjacent to lakes, streams and marshes, but information concerning them is not now at hand.

Flowing wells from deep wells drawing their supply from the St. Peter and Potsdam sandstones are known to occur only at one place in the county, at the Gault farm near Mukwonago. The head of this well is about 10 feet above the surface, an altitude of about 830 feet. Localities favorable to the development of flows may prevail along the Fox river valley up to altitudes of 830 feet. On the other hand, the water in the deep city wells at Waukesha, altitude of curb 815 feet, stands 40 feet below the surface, or only reaches a head of 775 feet, 20 feet lower than at Burlington, and over 50 feet below that at Mukwonago.

In the deep wells at Eagle, Menominee Falls and Oconomowoc the water stands from 38 to 15 feet below the surface.

SPRINGS

Springs are an important source of water supply in Waukesha county. They are especially abundant in the western part of the county in the zone of the outcrop of the Cincinnati shale. These springs issue either directly from the shale or from the overlying drift, or from the overlying Niagara limestone near the contact with the shale.

Near the base of the drift hills of the Kettle Range in the western part of the county springs are also of common occurrence.

Mineral springs furnishing large supplies of mineral water for the market are important, the various mineral springs at Waukesha being well known throughout America. (See list of Waukesha Springs, page 123). The Waukesha springs are examples of the numerous lime carbonate springs that issue at various points from the Niagara limestone. Mineral springs that formerly supplied the market are located in the vicinity of Pewaukee and Oconomowoc.

WATER SUPPLIES FOR CITIES AND VILLAGES

Waukesha. Waukesha, located on the Fox river, has a population of 8,740. The water supply is obtained from the river and five artesian wells. The average daily pumpage is 746,000 gallons. The sewage is

discharged into the Fox river, after being treated in a septic tank or filter bed. Only about 75 per cent of the houses are connected with the water supply and sewerage system.

The well water supply is obtained from 5 artesian wells, one 4½ inches in diameter and 1,500 feet deep, and four 6 to 10 inches in diameter and 1,000 feet deep.[1]

The water stands 40 feet below the surface when not pumping. With the air lift system, three of the 1,000 foot wells yielded 700 gallons per minute and the 1,500 foot well 225 gallons, at which rate the water was lowered 55 feet, to a depth of 95 feet.

The expense of operating the air pump was so great that two new wells were drilled, 12 feet apart, in which two continuous air pumps were installed, which furnished 700 gallons per minute with a lowering of 55 feet.

The strata passed through in the 1,500 foot well as reported by F. M. Gray of Milwaukee are as follows:

Log of Waukesha Well. Altitude of curb 815 feet.

Formation.	Thickness.
	Feet.
Drift	0
Niagara limestone	230
Cincinnati shale	160
Galena-Platteville (Trenton) limestone	300
St. Peter sandstone	60
Lower Magnesian limestone	80
Upper Cambrian (Potsdam) sandstone	670
Total depth	1,500

Oconomowoc. Oconomowoc situated on Lac La Belle, has a population of 3,054. The city water supply is obtained from a 10-inch well, 828 feet deep. The average daily pumpage is 114,000 gallons. A sewerage system was recently installed. The sewage is emptied without treatment into the Oconomowoc river a branch of the Rock river. About 50 per cent of the houses are connected with the water supply. Heavy pumping in the city well has not lowered the water more than 15 feet. The supply is used for all city purposes. Shallow private wells draw their water chiefly from the drift, and range in depth from 100 to 150 feet. A second well, 750 feet deep, was recently drilled for the water works.

Montgomery Ward has two deep wells at his summer home near the city, the logs of which are as follows:

[1] W. G. Kirchoffer, Bul. Univ. Wis., No. 106, p. 223.

Logs of Wells of Montgomery Ward, Oconomowoc.

Formation.	Well No. 1. thickness.	Well No. 2. thickness.
	Feet.	Feet.
Elevation of curb	890	896
Pleistocene.		
Yellow sand	40	30
Hard pan	100	120
Galena-Trenton.		
Limestone	254	260
St. Peter.		
Sandstone	100	80
Red sandstone	6	....
Depth	500	
Lower Magnesian.		
Limestone (sandy)	....	100
Upper Cambrian (Potsdam).		
Sandstone	....	310
Red marl	....	50
Hard sandstone	....	495
Hard gray rock	....	15
Pre-Cambrian.		
Very hard gray and red rock in layers of varying color	....	190
Depth	....	1650

Menomonee Falls. The population is 919. The Wisconsin Sugar Company in 1896 sunk a well in which it is reported, granite was struck at 1,375 feet. No record of the well is available, but the reported granite may be a buried knob similar to those occurring in the Fox river valley. It is possible also that the rock was a very hard sandstone such as that encountered in some of the wells farther south. In the latter case it is very probable that all the available water bearing rock was not penetrated, since the well had not penetrated more than the upper portion of the Potsdam sandstone. Besides this deep well the company has 4 other wells sunk into the limestone. An attempt is now being made to increase the supply to 400 gallons per minute by lengthening the pump shaftings and pumping the water from greater depths.

In the above 1375 foot well, F. M. Gray reports that 400 feet of sandstone was struck at 775 feet, and hard granite from 1175 to 1375 feet.

Eagle. Mr. W. L. Thorn, a driller at Whitewater, put in an artesian well at Eagle for the Chicago, Milwaukee and St. Paul Railway Company in 1903. Pumping 6,000 gallons per hour drew down the water from 38 to 87 feet below the surface.

Log of C. M. & St. P. R. R. Well at Eagle.

Formation.	Thickness.
	Feet.
Clay and gravel	130
Cincinnati shale, soft (cased)	120
Galena-Trenton.	
Light colored limestone	50
Blue limestone	237
St. Peter sandstone	20
Depth	557

Hartland. Hartland, with a population of about 800, has no public water supply. The wells are in drift and are usually about 30 to 60 feet deep.

Pewaukee. Pewaukee, located at the east end of Pewaukee lake, has no public water supply. The wells are usually in drift and are generally 20 to 40 feet in depth. The well at the Edgewood Farms near Pewaukee has the following log, as interpreted by F. T. Thwaites from examination of the driller's record and samples:

Log of Edgewood Farms Well, Pewaukee.

Formation.	Thickness.
Pleistocene:	Feet.
Gravel	50
Niagara:	
Very hard dolomite	130
Cincinnati:	
Shale with beds of limestone	205
Galena-Platteville:	
Very hard dolomite	215
St. Peter:	
White sandstone with seams of shale	59
Lower Magnesian:	
Sandstone with seams of limestone and shale	76
Potsdam:	
White sandstone	119
Red sandstone with seams of marl	50
Hard white to brownish sandstone, fine-grained and calcareous	146
Hard gray to brownish sandstone, somewhat coarser grained	165
Pre-Cambrian:	
Gray biotite granite	33
Total depth	1,248

In this well, it will be observed, the Pre-Cambrian was struck at a depth of 1215 feet without having penetrated the normal thickness of the Potsdam sandstone, indicating the presence of a buried knob of granite in this locality similar to those exposed in the Fox river valley

and encountered in some of the wells at Hartford and Menomonee Falls.

QUALITY OF THE WATER

Mineral analyses of various water supplies of Waukesha county are shown in the following tables. Many of the analyses, it will be noted, are of the various well known mineral springs located at Waukesha and in other parts of the county. Some of the analyses were made 40 or 50 years ago, while some are of recent date. In some instances where more than one analyses of a spring water is available, these show a close similarity in mineral content, while in other cases, considerable difference in the mineral content is indicated by the analyses.

All of the spring waters are calcium and magnesium carbonate waters, and in respect to hardness should be classed as either hard waters or very hard waters. Nearly all are of moderate mineral content, generally ranging between 254 and 462 parts per million. Two of the analyses, Nos. 9 and 17, are unlike the others in respect to mineral content as well as composition; No. 9 being very high in iron, and No. 17 high in magnesium sulphate. It is possible that these two may not represent natural waters but may have been treated in preparing for the market.

The mineral analyses of the well waters from the surface deposits and from deep wells reaching the St. Peter and the Potsdam sandstones show much the same content and characters of mineralization. All the well waters are calcium and magnesium carbonate waters of moderate mineral content, and nearly all are very hard waters. Waters obtained from the Cincinnati shale or adjacent formations are likely to be more highly mineralized with sulphates than those shown in the tables.

The water from the well of the Waukesha Spring Brewing Co., No. 33, contains 3.30 pounds of incrusting solids in 1,000 gallons, and that from the C. & N. W. Ry. well at Sussex No. 47, contains 4.26 pounds in 1,000 gallons.

Mineral analyses of water in Waukesha County.

(Analyses in parts per million)

	Springs.							
	1.	2.	3.	4.	5.	6.	7.	8.
Silica (SiO_2)	12.7	9.6	12.5	2.6	25.8	14.4	19.	12.
Aluminium oxide (Al_2O_3)	2.1	1.6	4.0	12.3	trace	4.	....	10.
Iron (Fe)	0.2	0.3	trace	3.1	trace	....	....	1.1
Calcium (Ca)	68.2	58.3	73.6	70.6	87.9	65.	70.6	67.9
Magnesium (Mg)	35.2	26.1	34.	37.3	41.3	30.	40.2	33.6
Sodium (Na)	17.7	6.8	8.	48.3	10.8	21.	16.5	14.7
Potassium (K)	3.5			6.2	7.4			
Carbonate radicle (CO_3)	200.8	158.	194.5	218.9	186.2	179.8	216.2	186.5
Sulphate radicle (SO_4)	9.6	4.2	14.3	68.4	75.1	11.	12.	3.4
Chlorine (Cl)	8.0	trace	1.8	13.0	28.0	7.	3.	19.9
Organic matter	34.	5.3	....	trace	trace	....	trace	....
Total dissolved solids	358.	265.	343.	481.	463.	332.	378.	740.

	Springs.						
	9.	10.	11.	12.	13.	14.	15.
Silica (SiO_2)	20.8	16.7	9.6	18.	18.	8.1	11.5
Aluminium oxide (Al_2O_3)	7.	7.2	2.6	....	1.0	1.5	1.5
Iron (Fe)	64.4	trace	0.6	trace	0.1	....	0.3
Calcium (Ca)	79.1	44.0	74.5	80.	47.6	56.9	68.7
Magnesium (Mg)	46.4	32.3	38.4	26.4	30.8	27.1	31.0
Sodium (Na)	76.8	2.8	10.8	22.7	8.9	19.0	7.1
Potassium (K)		1.3	2.2			15.9	3.5
Carbonate radicle (CO_3)	302.1	140.	208.8	195.	92.7	149.1	179.8
Sulphate radicle (SO_4)	96.8	10.9	2.8	12.6	58.7	35.3	14.8
Chlorine (Cl)	46.9	4.2	14.9	12.	38.8	14.5	3.2
Total dissolved solids	740.	259.	365.	367.	287.	328.	321.

NOTE: Phosphate radicle (PO_4) 0.5 in No. 4. trace in Nos. 1, 5, 11, 13, 14, 15.
Lithium (Li) 0.17 in No. 26, Trace in Nos. 10, 11.

1. Bethesda Spring, Waukesha, Analyst, C. F. Chandler, Geol. of Wis. Vol. 2, p. 146, 1877.
2. Fountain Spring, Waukesha, Analyst, J. V. Z. Blaney, Geol. of Wis. Vol. 2, p. 146, 1877.
3. Horeb Spring, Waukesha, Analyst, G. Bode, Geol. of Wis., Vol. 2, p. 146, 1877
4. Hygeia Spring, Waukesha, Analyst, O. A. Thiele.
5. Hygeia Spring, Waukesha, Analyst, W. S. Haines.
6. Lathean Spring, Waukesha, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 32, 1877
7. Mineral Rock Spring, Waukesha, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 31, 1877.
8. Silurian Spring, Waukesha, Analyst, W. S. Haines.
9. Waukesha Imperial Iron Spring, Waukesha, Analyst, G. N. Prentiss.
10. Waukesha Imperial Spring, Waukesha, Analyst, E. Hautke.
11. Waukesha Lithian Spring, Waukesha, Analyst, W. S. Haines.
12. White Rock Spring, Waukesha, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 146, 1877.
13. White Rock Spring, Waukesha, Analyst, O. Textor, 1899.
14. Crystal Rock Spring, Waukesha, Analyst, Davenport Fisher.
15. Arcadian Spring, Waukesha.

Mineral analyses of water in Waukesha County—Continued.

	Springs.						
	16.	17.	18	19.	20.	21	22.
Silica (SiO_2)	11.8	20.4	9.1	6.6	26.7	16.7	
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	2.4	....	....	....	....	7.
Aluminium oxide (Al_2O_3)	2.0		....	....	1.56	7.1	....
Iron (Fe)	0.4	....	0.6	0.7	0.7	trace	....
Calcium (Ca)	76.8	95.8	70.7	46.4	71.3	44.0	95.9
Magnesium (Mg)	35.5	72.6	57.2	34.9	36.3	32.7	23.6
Sodium (Na)	14.2	11.2	15.9	13.1	3.9	2.7	5.2
Potassium (K)	4.1				0.6	1.3	
Carbonate radicle (CO_3)	199.8	223.9	170.6	134.9	194.3	145.5	247.3
Sulphate radicle (SO_4)	26.2	157.7	50.1	44.0	17.7	9.4	24.2
Chlorine (Cl)	4.6	17.2	10.5	12.3	4.9	4.2	3.0
Total dissolved solids	375.	601.	385.	293.	358.	263.	406.

	Springs.						
	23.	24.	25.	26.	27.	28.	29.
Silica (SiO_2)	18.0	13.	16.	13.2	undt.	14.8	18.8
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)	....	....	....	....	....	18.9	2.5
Aluminium oxide (Al_2O_3)	2.0	3.	....	2.3	....	....	....
Iron (Fe)	0.3	3.1	....	0.7	....	....	....
Calcium (Ca)	83.5	61.6	72.0	56.7	77.4	65.2	75.1
Magnesium (Mg)	27.0	36.2	23.4	41.2	36.2	32.8	33.8
Sodium (Na)	21.5	6.4	19.	48.1	0.2	36.8	10.9
Potassium (K)				2.5		10.0	
Carbonate radicle (CO_3)	203.	197.2	174.2	233.6	174.7	216.6	198.9
Sulphate radicle (SO_4)	13.2	7.4	11.	10.6	26.0	24.5	22.1
Chlorine (Cl)	12.	1.8	11.	14.5	10.2	3.9	0.4
Organic matter	....	4.0	....	....	10.9	....	....
Total dissolved solids	381.	390.	327.	423.	336.	424.	363.

16. Clysmic Spring, Waukesha, Analyst, Joseph A. Deghuee.
17. Olivette Spring, Waukesha, Analyst, G. M. Davidson, Oct. 12, 1909.
18. White Rock Spring, Waukesha, Analyst, Laschè Institute, 1910.
19. Quarry Lake near White Rock Spring, Waukesha, Analyst, Laschè Institute, 1910.
20. Minniski Spring, Waukesha, Analyst, W. W. Daniells.
21. Fox Head Spring, Waukesha, Analyst, E. Hautke.
22. Brookfield Spring, Brookfield, Analyst, Chemist C. M. & St. P. Ry. Co., Mar. 29, 1899.
23. Nemahbin Spring, Delafield, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 31, 1877.
24. Oakton Spring, Pewaukee, Analyst, J. V. Z. Blaney, Geol. of Wis. Vol. 2, 1872.
25. Dausman's Trout Springs, Waterville, Analyst, G. Bode, Geol. of Wis. Vol. 2, p. 32, 1877.
26. "Soda Lithia Spring," near Fossville, Analyst, W. W. Daniells, 1892 or 1893, U. S. G. S. Folio 140.
27. Garrett's Flowing Spring, Brookfield, Analyst, G. N. Prentiss, Oct. 12, 1910.
28. Spring of Waukesha Springs Sanitarium Co., Waukesha, Analyst, Victor Lehner, Sept. 9, 1905.
29. Chalybeate Springs of B. M. Caples, one mile south of Waukesha, Analyst E. R. Hutchins, July 28, 1908.

Mineral analyses of water in Waukesha County—Continued.

	Rivers.			Lakes.			Surface deposits.	
	30.	31.	32.	33.	34.	35.	36.	37.
Depth of well..............feet..	....	....	....	....	....	....	25	20
Silica (SiO_2)......................	und't.	1.0	und't.	10.2	17.6	16.1	11.4	1.0
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)................	....	....	....	4.1	1.5	1.8	1.	....
Calcium (Ca)	54.5	43.9	55.1	22.7	34.3	40.3	88.1	78.1
Magnesium (Mg)................	30.1	30.8	35.4	19.0	25.9	28.0	39.7	44.8
Sodium (Na).....................	3.3	2.1	3.7	2.8	3.2	3.5	12.0	7.7
Potassium (K)...................				1.1	1.4	1.8		
Carbonate radicle (CO_3)..... ...	146.4	188.3	146.6	73.3	108.4	122.	188.3	202.3
Sulphate radicle (SO_4)...........	23.5	4.2	31.[illegible]	11.9	13.9	13.7	67.5	47.0
Chlorine (C).......................	und't.	3.2	9.1	5.5	4.0	5.5	19.9	6.3
Total dissolved solids........	258.	224.	282.	151.	210.	232.	428.	387.

	Surface deposits.						
	38.	39.	40.	41.	42.	43.	44.
Depth of well................. ....feet..	20	40	14	22	30	29	20
Silica (SiO_2) . Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)................	1.0	1.7	1.5	2.2	und't.	und't.	....
Iron (Fe)........................	....	....	....	....	....	....	1.2
Calcium (Ca)............................	73.3	85.6	74.2	82.7	81.4	91.0	71.7
Magnesium (Mg)....................	43.2	40.2	33.7	37.8	38.0	43.8	35.9
Sodium (Na) Potassium (K)............................	12.4	27.5	14.0	17.6	27.0	36.9	5.2
Carbonate radicle (CO_3).................	204.9	199.1	175.1	206.8	182.2	195.7	155.2
Sulphate radicle (SO_4)..................	45.0	70.5	48.1	27.8	108.9	61.0	70.0
Chlorine (Cl)............................	6.1	24.2	9.3	18.8	und't.	53.9	5.0
Nitrate Radicle (No_3)....................	....	....	....	....	....	24.7	....
Total dissolved solids...............	386.	449.	356.	393.	437.	507.	345.

30. Oconomowoc River, North Lake, Analyst, G. N. Prentiss, Nov. 26, 1900.
31. Oconomowoc River, North Lake, Analyst, G. N. Prentiss, Sept. 9, 1901.
32. Fox River, Brookfield, Analyst, G. N. Prentiss, October 15th, 1910.
33. Garvin Lake, Mean of 3 analyses, various depths, Analysts, E. B. Hall and C. Juday. Sept. 5, 1907. Wis. Survey Bull. 22, p. 170.
34. Okauchee Lake, Analyst, E. B. Hall and C. Juday, Sept. 5, 1907, Wis. Survey Bull. 22, p. 170.
35. North Lake, west part, mean of analyses, analysts, E. B. Hall and C. Juday, Sept. 4, 1907, Sept. 7, 1909. Wis. Survey Bull. 22, p. 170.
36. Well of the Waukesha Spring Brewing Company, Waukesha, Analyst, G. M. Davidson, May 24th, 1895.
37. Well of C. M. & St. P. Ry. Co., Brookfield, Analyst, Chemist, C. M. & St. P. Ry. Co., Aug. 31, 1889.
38. Well of C. M. & St. P. Ry. Co., Brookfield, Analyst, Chemist, C. M. & St. P. Ry. Co., Mar. 20, 1899.
39. Well of C. M. & St. P. Ry. Co. Eagle, Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 20, 1889.
40. Well of C. M. & St. P. Ry. Co., Genesee, Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 20, 1889.
41. Well of C. M. & St. P. Ry. Co., Oconomowoc, Analyst, Chemist C. M. & St. P. Ry. Co., Feb. 18, 1890.
42. Well of C. M. & St. P. Ry. Co., Oconomowoc, Analyst, G. N. Prentiss, May 4, 1900.
43. Well of C. M. & St. P. Ry. Co., Oconomowoc, Analyst, G. N. Prentiss, Aug. 16, 1907.
44. Well of C. M. & St. P. Ry. Co., North Lake, Analyst, G. N. Prentiss, Aug. 27, 1901.

Mineral analyses of water in Waukesha County—Continued.

	Surface deposits.			St. Peter and Upper Cambrian sandstone.			
	45.	46.	47.	48.	49.	50.	51.
Depth of well........feet..	20	14	15	135	820	679	1,375
Silica (SiO_2) / Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)........	1.0	3.1	1.7	und't.	und't.	14.03 / 1.37	11.4
Aluminium oxide (Al_2O_3)........	....	....	....	....	....	....	1.7
Calcium (Ca)........	97.4	100.2	82.9	72.2	60.1	111.63	31.9
Magnesium (Mg)........	45.5	45.2	45.1	40.0	34.2	43.63	22.6
Sodium (Na) / Potassium (K)........	27.8	12.9	26.7	9.4	10.8	11.55	7.0
Carbonate radicle (CO_3)........	206.2	187.1	153.1	159.6	183.6	179.22	96.8
Sulphate radicle (SO_4.)........	121.1	147.7	137.7	94.0	6.6	172.53	154.1
Chlorine (Cl)........	15.5	5.9	35.3	und't.	und't.	3.53	10.8
Organic matter........	....	....	....	....	....	....	9.9
Total dissolved solids........	514.	507.	482.	375.	295.	537.	337.

45. Well of C. M. & St. P. Ry. Co., Waukesha, Analyst, G. N. Prentiss, Nov. 14, 1896.
46. Well of C. M. & St. P. Ry. Co., Waukesha, Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 27, 1889.
47. Well of C. M. & St. P. Ry. Co., Peewaukee, Analyst, G. N. Prentiss, April 30, 1898.
48. Well of C. M. & St. P. Ry. Co., Lannon, Analyst, G. N. Prentiss, Nov. 28, 1900.
49. City Well, Oconomowoc Analyst, G. N. Prentiss, May 3, 1900.
50. Well of C. & N. W. Ry. Co., Sussex, Analyst, G. M. Davidson, Dec. 5, 1911.
51. Well of Wisconsin Sugar Co., Menominee Falls. Analyst, Chemist, C. M. & St. P. Ry. Co.

WAUPACA COUNTY

Waupaca county, located near the central part of the state, has an area of 749 square miles and a population of 32,782. About 85.9 per cent of the county is in farms of which 53 per cent is under cultivation.

SURFACE FEATURES

The surface of Waupaca county is undulating with gently sloping lands and broad valleys in the northern part, but somewhat more hilly and broken in the southern part. The land has a gentle slope to the southeast, being drained by the southeastward flowing streams in the southeastern part of the county. The altitude of the valley bottom of the Wolf river between Lake Poygan and New London is about 750 feet. The general altitude of the land in the northwestern part of the county ranges between 950 and 1,050 feet, the highest uplands and ridges reaching 1,100 to 1,200 feet. The range in elevation between valley bottom and adjacent uplands is generally between 100 and 200 feet.

GEOLOGICAL FORMATIONS

The geological formations are mainly the Upper Cambrian (Potsdam) sandstone and the surface deposits of drift and alluvium. The Pre-Cambrian granite occurs in the vicinity of Waupaca, and lies immediately beneath the drift in many places in the northwestern part of the county. In the southeastern corner of the county is a small area of Lower Magnesian limestone connected with the continuous body of this formation farther to the east. The geological structure is illustrated in Fig. 69.

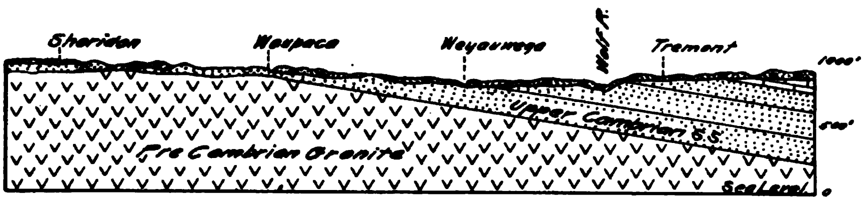

Fig. 69.—Geologic section, east-west, across southern Waupaca County.

The thickness of the surface formations is variable on account of the uneven surface upon which the deposits were laid, and also on account of the unequal deposition of drift. The known maximum thickness of the surface deposits is 214 feet at Weyauwega, but the preglacial valleys are likely to be over 300 feet deep.

The thickness of the Upper Cambrian (Potsdam) sandstone is quite variable on account of the extensive erosion of this formation. The complete thickness of the sandstone is preserved only in the southeastern part where it is protected by the overlying Lower Magnesian limestone. The approximate range in thickness of the geological formations in the county may be summarized as follows:

Approximate range in thickness of formations in Waupaca County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 350
Lower Magnesian limestone	0 to 100
Upper Cambrian (Potsdam) sandstone	0 to 500
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The chief water-bearing horizons are the "Potsdam" sandstone and the surface deposits of sandy alluvium and the drift. Most of the wells in the county are relatively shallow. The deepest wells range between 200 and 250 feet in depth.

FLOWING WELLS

At New London and Weyauwega and many other places along the Wolf river valley, artesian flows are obtained. Most if not all the flowing wells obtain their supply from the surface deposits. Most of these wells have a low head less than 10 feet above the surface. At Northport, however, the head of some of the important wells is between 25 and 30 feet above the surface. See also "Flowing wells along the Wolf river valley," pages 95–6.

WATER SUPPLIES FOR CITIES AND VILLAGES

Waupaca. The population if Waupaca, located on Waupaca River, is 2,789. The city water supply is obtained from a mill pond in the center of the city, and from a system of driven wells, and is pumped to a storage reservoir at a high elevation. The public water supply is used only to a very small extent for drinking purposes. The average daily pumpage is 243,000 gallons. The river supply is not filtered or otherwise purified, and is not satisfactory. The supply from ground water sources is from 20 wells, about 50 feet deep in sand. The Pre-Cambrian granite lies at the surface and immediately beneath the surface at Waupaca; hence ground water must be obtained at relatively shallow depths in the surface sand. With a properly arranged system of wells, however, there is no reason why an adequate supply of good ground water cannot be obtained. Private wells are generally from 10 to 30 feet deep. A sewage system was recently constructed, the sewage now being treated in two septic tanks and emptied into the Waupaca River. A large per cent of the families use the city water, and many have private sewers.

New London. New London, population 3,385, is located on Wolf River. This city has a city water supply and sewerage system. Formerly the water supply was obtained from Wolf River which did not prove satisfactory. An artesian source of water supply from flowing wells about 200 feet deep was recently placed in operation. The average

daily pumpage from the river was formerly about 80,000 gallons and only about 5 per cent of the residences connected with the city supply. Since the new artesian supply has been installed the use of the city supply has been greatly increased. A sewage system was recently installed, the sewage being emptied, without purification, into the river.

The water supply for drinking purposes, before the new artesian system was installed, was mainly taken from wells 20 to 40 feet deep. Some of the artesian wells on low ground near the river flow as high as thirteen feet above the surface. There are a number of flowing wells ranging from 110 to 220 feet in depth in the sand and gravel. (See Artesian Flows along Wolf River, pp. 95–6).

Clintonville. Clintonville, with a population of 1,747, has waterworks and sewage systems, the water being obtained from 6 shallow wells. About 35 per cent of the houses are connected with the waterworks. The sewage is emptied, without purification, into the Pigeon River.

Weyauwega. This village located on the Wolf river, has a population of 967. The water supply is obtained from open dug wells, many of which are 20 to 30 feet deep. There are a few bored wells 50 to 60 feet deep. There are a few flowing wells from the drift ranging in depth from 22 to 214 feet. Two of the flowing wells, 212 and 214 feet deep, reached the granite. The water in five of these flowing wells rises from 18 to 25 feet above ground. Three wells on Main Street, 30 feet deep, are used for fire purposes.

Northport. Population about 185. In Northport are four flowing wells owned by S. W. Fenton, H. M. Taylor, M. Babcock and Wm. J. Barlow, in which the water has a head from 20 to 27 feet above the surface. These wells are in sand and gravel from 60 to 110 feet deep.

Fremont. Population about 300. Two flowing wells in this village, 133 and 226 feet deep flow respectively 8 and 3 feet above ground.

Manawa. Population 820. The water supply is obtained from common wells 15 to 75 feet deep in sand and drift.

Iola. The village of Iola, population 850, is located on the south branch of the Little Wolf river. The water supply is obtained from common wells 30 to 70 feet deep, in clay and gravel.

Marion. The village of Marion, population 798, obtains its water supply from private wells 25 to 150 feet deep, in drift and granite, the latter forming a prominent ledge in the village.

QUALITY OF THE WATER

The mineral analyses of water supplies at New London and Clintonville are shown in the following table. The waters analyzed are hard waters of moderate mineral content, calcium and magnesium carbonates being the predominating constituents. These waters are quite similar in character and content of mineralization, and are probably typical for only a portion of the geological formations of the county. The supplies obtained from the granitic rocks, or from sand not associated with the red clays, or limestone-bearing drift, are likely to be less mineralized than those quoted in the table, and more like the waters analyzed from Waushara County, (p. 626). The water from Wolf River, and other surface supplies, probably contain about one-half as much mineral matter as the spring and well water quoted in the table below.

The spring water of analysis No. 1, contains 2.87 pounds of incrusting solids in 1,000 gallons of water; No. 2, contains 1.92 pounds, and No. 3, 1.72 pounds of incrusting solids in 1,000 gallons, and all would be classed as poor for boiler use.

Mineral analyses of water in Waupaca County.

(Analyses in parts per million)

	Lakes.			Spring.		Surface deposits.	
	1.	2.	3.	4.	5.	6.	7.
Depth of well ... feet	.....	.....	.....	.....	.....	32	20
Silica (SiO_2)	22.6	18.2	19.4	14.05	19.5	21.7	18.5
Aluminium and iron oxides (Al_2O_3 $+Fe_2O_3$)	2.2	2.5	2.2		8.0	3.7	2.0
Calcium (Ca)	45.7	31.8	22.2	63.87	67.5	70.9	69.5
Magnesium (Mg)	27.9	17.7	16.0	31.85	34.0	38.0	37.3
Sodium (Na)	2.4	3.0	2.3	2.91	5.2	9.0	4.5
Potassium (K)	2.0	3.1	3.3	.....			
Carbonate radicle (CO_3)	133.0	89.0	69.2	160.44	191.9	163.3	191.9
Sulphate radicle (SO_4)	10.5	10.4	8.8	22.42	32.3	59.1	6.9
Chlorine (Cl)	2.4	2.5	4.2	4.45	4.8	13.9	6.9
Total dissolved solids	249.	178.2	147.6	300.	358.	380.	338.

1. Lake Beasly, mean of 3 analyses, Analysts, E. B. Hall and C. Juday, Sept. 9, 1907, Wis. Survey Bull. 22, p. 170.
2. Long Lake, mean of 2 analyses, Analysts, E. B. Hall and C. Juday, Sept. 9, 1907, Wis. Survey Bull. 22, p. 170.
3. Rainbow Lake, mean of 2 analyses, Analysts, E. B. Hall and C. Juday, Sept. 10, 1907, Wis. Survey Bull. 22, p. 170.
4. Spring of C. & N. W. Ry. Co., New London, Analyst, G. M. Davidson, May 28, 1912.
5. Spring of Wisconsin Chair Co., New London, Analyst, G. M. Davidson, Oct. 29, 1903.
6. Well of C. & N. W. Ry. Co., Clintonville, Analyst, G. M. Davidson, May 24, 1909.
7. Drive well 75 ft. W. of C. & N. W. Ry. Co., Freight Depot, Clintonville, Analyst, G. M. Davidson, Aug. 1895.

WAUSHARA COUNTY

Waushara county, located in the central part of the state, has an area of 639 square miles and a population of 18,886. About 88.6 per cent of the county is in farms of which 61.8 per cent is under cultivation.

SURFACE FEATURES

The surface of Waushara county is undulating, consisting of valley bottom lands and sloping uplands. The western border of the county in the locality of Plainfield and Hancock is a level alluvial plain, like that over much of Adams county. The billowy drift hills of the ter-

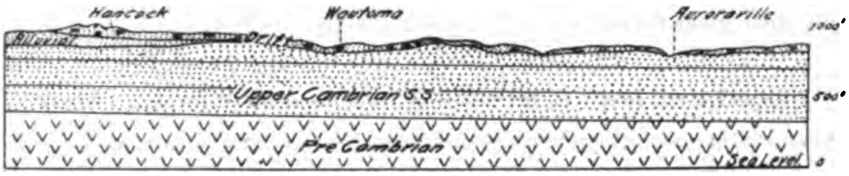

Fig. 70.—Geologic section, east-west, across central Waushara County.

minal moraine of the Green Bay lobe extend north and south across the western part of the county at Coloma, and a short distance east of Plainfield. West and north of Wautoma the land rises in a series of bluffs reaching its greatest height about ten miles from Wautoma and forming the divide between the waters of the Wisconsin river flowing towards the west and those of the Wolf river flowing towards the east. To the south and east of Wautoma the land descends to the Fox river and Lake Poygan in the eastern part of the county.

The altitudes range from about 750 feet along the Fox river and Lake Poygan to about 1,200 feet in the western part on the divide between the Wolf and the Wisconsin rivers. In the valley bottoms near Fox river and Lake Poygan red and dark colored clay soils occur. Over the remaining parts of the county, loams, sandy loams and sandy soils prevail.

GEOLOGICAL FORMATIONS

The principal geological formations outcropping at the surface or lying immediately beneath the surface deposits of drift and alluvium is the Upper Cambrian (Potsdam) sandstone. The only other rock for-

mation in the county is the granite occurring as isolated mounds and knobs in the vicinity of Red Granite and Pine River. The geological section is shown in Fig. 70.

Red lacustrine clays are quite prevalent in the valleys in the eastern part of the county. The clays appear at the surface and are also interstratified with beds of sand and gravel to a variable depth, developing good artesian slopes in which numerous excellent surface flowing wells have been obtained. The thickness of the surface clays and gravels in the valleys is variable and probably reaches a maximum of 250 to 300 feet. The thickness of the glacial drift ranges from a few feet up to over 100 feet in the morainic belt, extending across the western part of the county. The thickness of the sandstone is very irregular on account of the extensive erosion of the strata before the surface formations were deposited upon it. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Waushara County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Upper Cambrian (Potsdam sandstone)	0 to 750
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

The water-bearing formations are the "Potsdam" sandstone and the surface deposits of the glacial drift and the alluvial sands and gravels. These formations are excellent water bearing strata and furnish an abundant supply of water. On the top of the divide between the Wolf and Wisconsin rivers the depth to water is 100 to 150 feet, the wells generally penetrating some depth into the sandstone formation. On lower ground in the valleys shallow wells in the surface deposits are most common.

The granite formations outcropping in the eastern part of the county can furnish but a small supply, though, where necessary, sufficient for farm purposes can be obtained.

FLOWING WELLS

Flowing wells from the surface deposits in the wide valleys adjacent to Lake Poygan constitute an important source of supply. In this locality artesian slopes are deveolped by the superposition of relatively impervious clay beds over pervious beds of sand and gravel, the strata dipping gently down the valleys towards the lake. The water in the sand and gravel under the clay beds is under sufficient pressure to rise above the surface a few feet on the bottom and lower slopes of the valleys.

The flowing wells at Aurorahville on Willow Creek have been in use for many years. This area of flowing wells in eastern Waushara county is characteristic of large portions of the Fox River valley and is more fully described in another place (See pages 92–5).

SPRINGS

Springs are a common source of water supply in the valleys in the eastern part of the county. On higher land in the central part where sandstone outcrops along the streams springs are likely to occur. A well known mineral spring is located at Wautoma.

WATER SUPPLIES FOR CITIES AND VILLAGES

Wautoma. The population of Wautoma is 964. The wells are generally driven wells. There are some very low places in the village where the water level is very close to the surface, but in most places it is at a depth of from 10 to 20 feet. The fire department, equipped with a gasoline engine, obtains its water supply from a well about 15 to 20 feet deep and 10 to 12 feet in diameter. The well has not been pumped dry, although at times it is drawn down about 10 feet.

Plainfield. The population is 723. The water supply is obtained from private wells, 20 to 60 feet deep in sand and gravel.

Aurorahville. There are a number of flowing wells in Aurorahville that obtain their supply from alluvial sand and gravel. The wells are in the shallow artesian slope in the valley of Fox River and are more fully described in another place. (See page 92).

QUALITY OF THE WATER

The mineral analyses of the various water supplies of Waushara county are shown in the following table. All the waters are hard waters of moderate mineral content. Calcium carbonate is the predominant constituent. The spring water at Wautoma is the highest in mineral content and is relatively high in iron and manganese. The surface waters from White River and the creek at Red Granite Junction are very similar in content of mineralization to the well waters in surface deposits. The various analyses in the table are probably typical in a general way for most of the county. Waters from deep wells in the sandstone, or from surface sands associated with or below red clays, are likely to be higher in mineral content than those quoted in the table. The water from the well in Wautoma, No. 4, contains 1.33 pounds of incrusting solids in 1,000 gallons.

Mineral analyses of water in Waushara County.

(Analyses in parts per million)

	Rivers.		Spring.	Surface deposits.		
	1.	2.	3.	4.	5.	6.
Depth of well.................. feet..	....	....	....	28.	94.	297.
Silica (SiO_2)........................	13.9	11.4	27.9	12.0	12.1	12.3
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)........................	1.5	Trace.	....	35.6	3.4	1.8
Aluminium oxide Al_2O_3)............	....	....	4.2	....	....	....
Manganese (M)........................	....	....	6	....	....	....
Iron (Fe)........................	....	....	2.1	....	....	....
Calcium (Ca)........................	46.4	35.0	50.8	44.3	31.6	44.8
Magnesia? (Mg)........................	26.3	18.7	23.8	8.7	18.6	25.2
Sodium (Na)........................ Potassium (K)........................	1.8	7.5	4.1 1.5	5.2	3.3	1.5
Carbonate radicle (Co3)........................	135.5	82.	142.1	85.2	83.5	129.2
Sulphate radicle (SO_4)........................	....	10.8	1.3	10.5	....	....
Chlorine (Cl)........................	2.8	2.8	.5	3.5	5.2	2.4
Total dissolved solids....	228.	168.	258.	233.	158.	217.

1. White River, Wautoma, Analyst, G. M. Davidson, March, 1901.
2. Creek outlet of lake at Red Granite Jct., Analyst, G. M. Davidson, Dec. 1901.
3. Rainbow Spring ,Wautoma, Analyst, W. W. Daniells.
4. Well of C. & N. W. Ry. Co., Wautoma, Analyst, G. M. Davidson, March, 1901.
5. Well of C. & N. W. Ry. Co., Wild Rose, Analyst, G. M. Davidson, Feb. 11, 1901.
6. Well of C. & N. W. Ry. Co., Wild Rose, Analyst, G. M. Davidson, Jan. 1902.

WINNEBAGO COUNTY

Winnebago county, located on the west side of Lake Winnebago in the east central part of the state, has an area of 472 square miles and a population of 62,116. About 88.7 per cent of the county is in farms. of which 72 per cent is under cultivation.

SURFACE FEATURES

The surface of the county is quite gently sloping with slightly undulating and hilly areas in the western part. The land has a gentle slope to the east toward Lake Winnebago. The broad gently sloping depression occupied by Lake Butte des Morts, and Lake Poygan extends westward through the central part. A belt of hummocky drift hills trends north and south through the central part.

The elevation of Lake Winnebago is 746.1 feet and of Lake Poygan 746.6 feet above the sea, about 166 feet above Green Bay and Lake Michigan. The land surface is characterized by moderate reliefs only, the highest ridges and uplands probably rarely exceeding 200 feet above Lake Winnebago.

GEOLOGICAL FORMATIONS

The geological formations are the Upper Cambrian (Potsdam) sandstone, the Lower Magnesian limestone, the St. Peter sandstone and the Galena-Platteville (Trenton) limestone. The area of outcrop of these formations forms belts trending northeast-southwest, the Upper Cambrian sandstone being in the western part of the county and the Galena-Platteville limestone in the eastern. Over these rock formations is a variable amount of glacial drift and river sand, and silt. The red lacustrine clay is the prevailing surface formation, very generally occupying the basin of Lake Winnebago and the Fox river. The geological structure is illustrated in Fig. 71.

The thickness of the surface formations is variable on account of the uneven surface of the rock formation upon which they are deposited. In the valleys of the pre-glacial rivers a thickness of 200 to 300 feet of river sand, gravel and clay may be expected. This condition is indicated by a deep well at Winneconne, which penetrated 190 feet of alluvial deposit before reaching the sandstone. Outside

the buried pre-glacial valleys the glacial drift and other surface deposits are usually less than 100 feet in thickness.

The thickness of the rock formations is also quite variable on account of the unequal erosion of the strata, and also in part on account of variation in thickness of strata originally deposited. The Pre-Cambrian

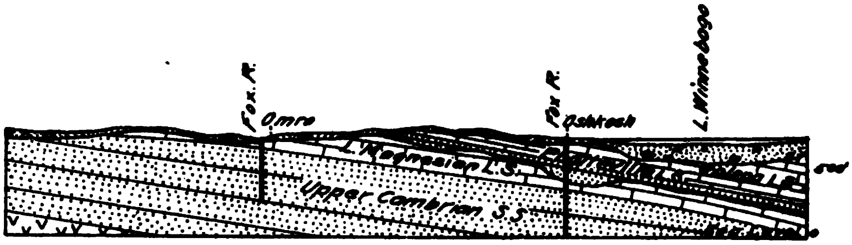

Fig. 71.—Geologic section, east-west, across southern Winnebago County.

granite floor lies at a depth of 426 feet below the surface at Winneconne, and at a depth of 680 to 714 feet below the surface at Oshkosh. The character of the Lower Magnesian and St. Peter varies as in all other parts of the state, and consists largely of limestone in some places, and largely of sandstone and shale in other places. In some of the wells in Oshkosh, as at the city well on Algoma street, the Lower Magnesian formation consists largely of limestone, but in most other wells in the city the Lower Magnesian horizon appears to be largely sandstone and shale. The base of the Galena-Platteville (Trenton) limestone in Oshkosh appears to be reached at a depth of 70 to 125 feet below the surface, below which the strata are usually, as shown in the well records cited on page 631, either sandstone or sandstone and shale, until the Pre-Cambrian is reached. The approximate range in thickness of the geological formations in the county may be summarized as follows:

Approximate range in thickness of formations in Winnebago County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 300
Galena-Platteville (Trenton) limestone	0 to 200
St. Peter and Lower Magnesian	150 to 200
Upper Cambrian (Potsdam) sandstone	400 to 500
Pre-Cambrian granite	....

PRINCIPAL WATER-BEARING HORIZONS

All the geological formations are drawn upon for water supplies, but the most important sources are the surface deposits of sand and gravel under the red clay, and the sandstone which outcrops in the western part of the county and underlies the limestone in the eastern part. The limestone of the Lower Magnesian and the Galena-Platteville formations in the areas of their respective outcrop also yield abundant supplies from the open fractures and fissures which extend throughout these formations. Most of the wells in Oshkosh, as at Fond du Lac, appear to indicate that the usual horizon of the Lower Magnesian formation is occupied by the St. Peter formation and conists largely or entirely of sandstone strata as the wells after passing through the Trenton limestone, penetrate a thickness of 300 to 400 feet of sandstone. The Pre-Cambrian granite in Oshkosh is struck at depth of about 700 feet.

FLOWING WELLS

Flowing wells are quite common in Winnebago county on low ground adjacent to Lake Winnebago, Lake Poygan and the Fox and Wolf rivers, the flows being obtained from the surface deposits and from the underlying rock. The head of the sandstone water is relatively low, usually not exceeding 10 or 15 feet above Lake Winnebago at Oshkosh and Menasha, but rising higher up the valley of the Fox, being about 17 feet above the river at Omro. The head, however, is controlled largely by local conditions within the surface deposits of sand and red clay. (See pages 90–2).

The water in the many flowing wells in Oshkosh is obtained from three horizons, namely: from gravel beds at base of the drift—from the limestone—and from the sandstone, either from the St. Peter or the Upper Cambrian (Potsdam), or both combined. The flows from the drift are obtained chiefly on the south bank of Fox river, many being located between Nebraska, Oregon, and East Main streets. Most of the other wells have their source in the underlying sandstones. Many of the wells would not flow until packed, owing to leakage in the limestone.

SPRINGS

Springs are quite common in Winnebago county on low ground adjacent to the Fox river. Near Oshkosh are several well known mineral springs supplying a large local demand, as well as outide markets. The springs issue either at the contact of the Trenton limestone with the overlying drift, or from the limestone.

WATER SUPPLIES FOR CITIES AND VILLAGES

Oshkosh. This city, located on Lake Winnebago, at the mouth of the upper Fox River, has a population of 33,062. The city water supply, originally, was wholly obtained from eight artesian wells 300 to 900 feet deep, but on account of apparent lack of sufficient quantity, most, if not all, the supply is now taken from Lake Winnebago. The lake water is obtained from a point 1,000 feet from shore, at a depth of 18 feet, about as deep as any place in the lake. The average daily pumpage is 2,424,000 gallons. A filter was recently installed, which has been increased in capacity to 4,500,000 gallons per day, and settling basins have been constructed.

The city sewage is emptied, without purification, into the lake and the Fox river. Outside the business district only 30 or 40 per cent of the houses have sewer and water connections.

At Oshkosh between 25 and 50 flowing wells have been obtained. Most of these within the city are located south of the river in South Oshkosh and along the river banks. The lowlands in the vicinity of Oregon and Nebraska streets, as well as nearer the lake and river, are favorable for flows and within this area 20 to 25 wells have been drilled.

There has been considerable discussion as to the thickness and stratigraphic position of the formations penetrated in the artesian wells drilled in Oshkosh and vicinity. (See accompanying table of Oshkosh wells). Until this matter is decided it is unnecessary to enter into the details of the problem in this report. There appears, however, to be only about 400 feet of the Potsdam at Oshkosh.

Sections of Wells at Oshkosh, Records Furnished by G. Muttart.

Owner.	Drift.	Lime-stone.	Sand-stone.	Granite.	Total depth.
	Feet.	Feet.	Feet.	Feet.	Feet.
Winnebago Asylum	30	40	150	....	220
Winnebago Poor Farm	30	42	184	....	256
Winnebago Workshop	10	40	40	....	90
J. P. Gould	20	50	385	....	455
Radford Bros	50	60	313	....	423
Wm. Gladts	present..	present..	136	....	426
M. Hooper	20	100	90	....	210
Gillan Bros	50	60	95	....	205
Tremont House	80	30	16	....	126
C. Foster	10	58	....	....	68
Hollister Ames	60	30	85	....	175
Lutheran Cemetery	25	100	70	....	195
Judge Washburn	106	....	129	....	234
Commercial House	100	....	78	....	178
Fowler House	95	....	39	....	134
Horns Brewery	10	100	180	....	290
S. Hollister	50	60	315	....	425
Benderov, Chase Co	39	present..	present..	....	185
Ed. Couske	40	41	....	....	81
Northern Hospital[1]	60	240	414	248	962
Algoma Street[1]	92	208	380	15	695

[1] Geology of Wisconsin, Vol. II, pp. 156-158.

Winneconne. The population is 940. The water supply is from private wells, 20 to 40 feet deep, many of which are flowing. The record of one of the flowing wells, one foot head, drilled by Wm. Miller, is as follows:

Section of well drilled by Wm. Miller, 1888.

Formation.	Thickness.
	Feet.
Clay	30
Gravel and sand (abundant water rose to 6 feet)	6
Clay, gravel	84
Gravel and sand (flow?)	40
Clay	30
Upper Cambrian (Potsdam) sandstone, flows at 210 feet, rise to 2 feet above curb.	236
Granite. (bottom of well)	....
Total	426

Further drilling did not increase the head, but there was a decided increase in quantity.

Many other flowing wells are found in and about Winneconne that get their flow from gravel and sand seams in the drift. (See page 93).

Omro. At Omro the water supply is obtained from three sources, the Potsdam sandstone, the Lower Magnesian limestone, and the sand

and gravel seams in the drift. Since the limestone in the valley is only 10 to 20 feet thick and the water is obtained from crevices, it may be supplied either by sandstone below or by gravel above. Numerous shallow artesian wells are found along the banks of the Fox river. Between the two creameries, a distance less than half a mile, are seven flowing wells.

In the shallow flowing wells are found about 20 feet of red clay, overlying 6 feet of hard pan, and 2 feet of sand.

Section of Abe McAssay's Artesian Well, Omro.

Strata.	Thickness.
	Feet.
Clay	30
Hardpan	48
Lower Magnesian limestone	20
Upper Cambrian (Potsdam) sandstone	360
Depth	458

Neenah. The population of Neenah is 5,734. The water supply was originally taken from Lake Winnebago, but at present it is obtained from three 6-inch artesian wells, one 400, the others 622 and 672 feet deep. The average daily pumpage is 432,000 gallons. About 40 to 50 per cent of the houses are connected with the city supply. The sewage, without treatment, empties into the lake. Cess pools are not allowed. The three city wells draw their water from both the St. Peter and Upper Cambrian horizons. The level of the water in the wells varies with the elevation of the water in the lake. When a strong wind from the east or southeast drives the water higher against the shore the water in the wells rises. Since the well casing extends a short distance into the rock the water readily finds a passage through the porous sandstone or limestone into the lake, and therefore, will not rise higher than the latter. A part of the water may thus be lost by seepage into the lake either from the sandstone or from the Trenton limestone. There is little doubt but what the water in the lake maintains the head of the water in the wells, although the well water is entirely supplied by the St. Peter and Upper Cambrian aquifers, unless through pumping the water in the wells is kept far below the surface. The wells are 50 feet apart in a northwest-southeast direction, and the water flows into a reservoir 20 feet deep that rests on rock and holds 190,000 gallons.

The pipe by which the water from the new well enters the reservoir is 8 feet higher than the pipe from the old well which enters at the bottom of the reservoir 20 feet below the surface. When the water is pumped down to the bottom of the reservoir the new well is shut off and only the supply from the old well is used, since lowering the water in one well lowers it an equal amount in the other. The daily capacity of the wells is about 800,000 gallons.

Log of Neenah city well.

Formation.	Thickness.
	Feet.
Drift	18
Galena-Platteville (Trenton) limestone	87
St. Peter sandstone	27
Lower Magnesian limestone	116
Upper Cambrian (Potsdam) sandstone.	
Red marl	33
White sandstone	28
Red sandstone and marl	43
Sandstone	56
Blue limestone	8
Sandstone	206
Total depth	622

Besides these city wells there are a few others that get their supply from the Trenton limestone or pass directly from the drift, which here varies greatly in thickness, into the St. Peter sandstone. Three records will be given showing these conditions. The two wells of G. Donald's flow 5 feet above the surface.

Sections of Neenah wells.

Owner.	Drift.	Trenton limestone.	St. Peter sandstone.	Total depth.
	Feet.	Feet.	Feet.	Feet.
Mr. Davis	32	48	....	80
G. Donald	113	0	83	196
G. Donald	113	0	92	205

Menasha. The population of Menasha is 6,081. The city water supply is obtained from the Fox river, depth of intake being 12 feet. The average daily pumpage is 336,000 gallons. About 35 per cent of the

houses are connected with the city supply. The sewage, without treatment, empties into the Fox River, below the intake.

There are several flowing wells in Menasha. The well drilled by the Gilbert Paper Company, 575 feet deep, was never cased and soon filled up. There was too much iron in the water to use it for paper manufacture, but for drinking purposes the water was excellent. In the other deep wells the water is obtained from the St. Peter sandstone, as in that of V. Landgraf, 275 feet deep, and of Wm. Hewitt, 500 feet deep. The conditions for underground water supplies in Menasha are the same as in Neenah, as above described.

QUALITY OF THE WATER

The mineral analyses of various water supplies of Winnebago county are shown in the following tables. Nearly all the waters analyzed are hard calcium and magnesium carbonate waters of moderate mineral content. The surface waters from the Fox river and Lake Winnebago, which furnish the city supplies for Menasha and Oshkosh, contain about one-half as much mineral matter as the well waters of the adjacent locality. For boiler purposes, therefore, the surface waters are better than the well waters, but surface waters are likely to become polluted by organic matter and the development of bacteria, and hence do not furnish as good a supply for drinking purposes.

There are about 1.36 pounds of incrusting solids in 1,000 gallons of the Lake Winnebago water, as shown in No. 8, only slightly more than that in Lake Michigan water, while the well waters generally contain 2 to 3 pounds of incrusting solids in 1,000 gallons.

Mineral Analyses of Water in Winnebago County.

(Analyses in parts per million)

	Fox River.					Lake Winnebago.			
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Depth of well.........feet..	....	....	......	—?	—?	......	......	......	—?
Silica (SiO_2)........			4.4			6.9	8.9	3.9	
Aluminium and iron oxides (Al_2O_3)........	undt.	undt.	10.	undt.	undt.	3.6	2.4	1.5	undt.
Calcium (Ca)........	34.0	26.2	23.0	33 9	34.4	35.4	32.8	33.4	26.2
Magnesium (Mg)........	19.1	12.4	15.6	19.0	18.4	20.4	16.2	19.0	12.4
Sodium and potassium (Na+K)	14.4	6.7	14.1	18.5	4.2	8.7	5.9	9 4	6.9
Carbonate radicle (CO_3)........	107.0	66.4	83.8	110.8	90 0	101.8	61.6	88.4	66.4
Sulphate radicle (SO_4)........	6.6	10 9	7 6	6.0	11.9	13.9	49.3	29.2	10.9
Chlorine (Cl)........	5.1	6.2	3 5	6.1	5.2	5.3	5.3	6.4	6.2
Organic matter........	....	....	10.	....	....	8.	8.	......	....
Suspended matter........	....	....	......	....	....	......	12.	......	....
Total dissolved solids........	186.	129.	162.	194.	164.	196.	182.	192	129 0

	Surface deposits.						
	10.	11.	12.	13.	14.	15.	16.
Depth of well.........feet..	26	14	16	22	12	25	95
Silica (SiO_2)........ Aluminium and iron oxides (Al_2O_3+Fe_2O_3)........	3.4	7:5	8.5	2.3	11.4	undt.	3.9
Iron (Fe)........	....	....	0.4	....	....	....	....
Calcium (Ca)........	106.0	15.1	83.5	34.6	66 7	73.1	77.5
Magnesium (Mg)........	53.5	53.0	16.0	42.8	39.1	48.2	37.6
Sodium and potassium (Na+K)........	25.3	58.9	3.7	4.6	15.0	5.5	9.5
Carbonate radicle (CO_3)........	277.7	142.	253.0	159,0	191.8	173.2	190 3
Sulphate radicle (SO_4)........	58.2	137.	5.2	7.5	31.8	61.0	30.7
Chlorine (Cl)........	12.2	3.2	1.8	1.5	5.5	18.8	14.6
Nitrate radicle (NO_3)........	....	....	....	....	....	15.0	....
Total........	536.	417.	372.	251.	361.	395.	364.

1. Fox River at Menasha, Analyst, G. N. Prentiss, Feb. 6, 1909.
2. Fox River at Oshkosh, Analyst, G. N. Prentiss, April 28, 1913.
3. Fox River at Menasha. City Water Supply, Analyst, Dearborn Drug & Chem. Co., Nov. 11, 1907.
4. City Water Supply, Menasha, Analyst, G. N. Prentiss, Feb. 6, 1909
5. City Water Supply, Menasha, Analyst, G. N. Prentiss, June 29, 1911.
6. Lake Winnebago, City Water Supply, Oshkosh, Anolyst, Dearborn Drug & Chem. Co., Jan. 17, 1911.
7. Lake Winnebago city supply after passing through water works filter system. Analyst, Dearborn Drug & Chem. Co., Nov. 21, 1911.
8. Lake Winnebago, Oshkosh, Analyst, G. M. Davidson, June 23, 1896.
9. Lake Winnebago, city water supply. Oshkosh from Paine Lumber Co., Analyst, G. N. Prentiss, April 28, 1913.
10. Well of C. M. & St. P. Ry. Co., Menosha, Analyst, Chemist, C. M. & St. P. Ry. Co., July 13, 1891.
11. Well of C. M. & St. P. Ry. Co., Menasha, Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 8, 1889.
12. Well of Mr. Wadkins, Oshkosh, Analyst. A. R. Nintze.
13. Well of C. M. & St. P. Ry. Co., Winneconne, Analyst, Chemist, C. M. & St. P. Ry. Co., Sept. 9, 1889.
14. Well of C. M. & St. P. Ry. Co., Oshkosh, Analyst, Chemist, C. M. & St. P., Aug. 10, 1889.
15. Well of C. M. & St. P. Ry. Co., Oshkosh, Analyst, G. N. Prentice, Mar. 21, 1912.
16. Well of C. M. & St. P. Ry. Co., Picketts, Analyst, Chemist, C. M. & St. P. Ry., Aug. 12, 1889.

Wood County

Wood county, located in the central part of the state, has an area of 785 square miles, and a population of 30,583. About 54.8 per cent of this county is laid out in farms, of which 38 per cent is under cultivation.

SURFACE FEATURES

The surface of Wood county is a nearly level plain gradually rising to the highest land in the northwestern part of the county, where the glacial deposits are relatively thick. The southern part of the county is a level sandy plain containing large areas of marsh land requiring drainage. Elevations vary from 1,000 feet in the southern part to over 1,300 feet above sea level in the northwestern part, about Marshfield. Powers Bluff, near Arpin, is a prominent ridge of quartzite, rising 300 to 400 feet above the adjacent area. The upland soils are very generally silt loams and sandy loams. Light phases of sandy soils characterize the level plains in the southern part of the county.

GEOLOGICAL FORMATIONS

The geological formations (see Fig. 61) are like those of Portage county, the crystalline formation either outcropping or being near the surface in the northeastern part of the county. Glacial drift is in thick deposits only in the northwestern part of the county, and the alluvial gravel and sand is abundant along the Wisconsin and Yellow rivers in the southern part of the county.

The thickness of the surface formation of glacial drift and alluvial sands is quite variable. The maximum thickness of the drift is between 150 and 200 feet, and a similar thickness of the alluvial filling in the principal valleys also prevails. The thickness of the Upper Cambrian (Potsdam) sandstone is variable on account of the extensive erosion of the strata, the greatest thickness being preserved in the sandstone mounds and ridges. The approximate range in thickness of the geological formations may be summarized as follows:

Approximate range in thickness of formations in Wood County.

Formation.	Thickness.
	Feet.
Surface formation	0 to 250
Upper Cambrian (Potsdam) sandstone	0 to 250.
The Pre-Cambrian granite	....

WATER-BEARING HORIZONS

The water bearing strata are mainly the alluvial sands, the glacial drift and the sandstone formation. Most streams have cut down to the crystalline rocks and most wells are very shallow. On the highest drift covered uplands near Marshfield, a few wells are from 100 to 200 feet deep in drift.

WATER SUPPLIES FOR CITIES AND VILLAGES

Grand Rapids. This city having a population of 6,521, is located on the Wisconsin river, on the site of extensive water power. Crystalline rock, partly weathered to clay, outcrops along the bed of the river. No sandstone is reported in the city, but a few miles to the north and the west it forms prominent ridges. Alluvial sand and gravel lies di-

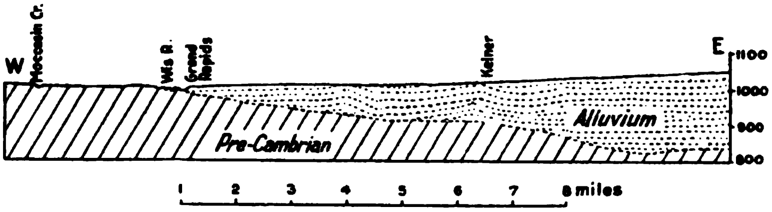

Fig. 72.—Geologic section in the vicinity of Grand Rapids showing the relation of the alluvial sand and gravel to the Pre-Cambrian granite.

rectly upon the crystalline rocks to a depth of 10 to 30 feet in the eastern part of the city, and gradually increases in depth to the south and east. See Fig. 72. The private wells are from 20 to 40 feet deep. At the present time the city water supply recently installed is obtained from a system of shallow wells or springs 6 to 24 feet deep, located near the river. An intake from the river is connected with the system to be used in case of emergency. The average daily pumpage is

300,000 gallons. About 40 per cent of the houses are connected with the city supply. The sewage is emptied into the river.

The city supply was increased in 1913 by installing a pumping station connected with a system of shallow wells in the sand in the eastern part of the city.

Marshfield. Marshfield, having a population of 5,783, is located upon a relatively thick clayey drift ridge, which gently slopes towards the south and the north. The private wells in the city vary in depth from 10 to 20 feet up to 95 feet. The depth of drift over the granite varies from 40 to 90 feet. The large well of the Upham Manufacturing Company, the deepest well in the city, has a total depth of 130 feet, 90 feet in drift and 40 feet in the granite. An increase in the supply was obtained up to a depth of 20 or 30 feet in the granite, but little or no increase beyond that depth.

The present city water supply[1], reconstructed in 1907 and 1908, consists of a tubular well system connected with an impounding reservoir located in the southern part of the city. There are 16 wells, 12-inch casing, driven to the granite rock 58 to 70 feet deep, spaced 35 to 40 feet apart. The drainage area feeding into the surface gravel and sand, in which the system is located, is about 417 acres. To provide for impounding the surface water to form an auxiliary supply, a dam 1,700 feet long was built across the small creek valley. The average daily pumpage is 350,000 gallons.

The sewerage is treated with septic tanks and filters, and empties into the creek below the dam.

Pittsville. Pittsville, (population 450) is located on a plain on Yellow river. Granite outcrops along the river, but away from the river the granite is usually effectually covered with the beds of sandstone, and shallow deposits of surface clay and sand from 5 to 15 feet thick. The wells are quite generally shallow, from 10 to 30 feet deep.

Nekoosa. Nekoosa (population 1,750) is located on the Wisconsin river at the site of extensive water power. Granite forms the bed of the river, with the formation of sandstone and alluvial sand and gravel overlying the granite. The wells are generally shallow, from 10 to 30 feet deep.

A city supply was recently installed, the supply being obtained from a 60 foot well, 40 feet in sand and gravel and 20 feet in the underlying granite. This supply, however, was unsatisfactory, the water being high in iron. A new and satisfactory supply is now being installed, the source of the supply being several springs located near the western part of the village.

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[1] W. G. Kirchoffer, Wis. Municipality, Vol. XI, pp. 114–119, 1911.

QUALITY OF THE WATER

The mineral analyses of various water supplies of Wood county are shown in the following table. Some of the waters analyzed are hard waters, while some are soft. All are calcium carbonate waters of either low or moderate mineral content. Alkalies are a relatively important constituent on account of the presence of the crystalline schists and granitic formations that are generally near the surface.

The analyses, Nos. 1 and 2 are of the former city water supply of Grand Rapids. Analysis No. 3, is of the present city supply of Marshfield and shows this water to contain only 1.41 pounds of incrusting solids in 1.000 gallons.

Mineral analysis of water in Wood County.

(Analyses in parts per million)

	Wisconsin River.		Surface Deposits—alluvial sand.							
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Depth of well.............feet..	......	......	36	22	22	22	22	55	60	61 & 74
Silica (SiO_2)....................		15.92	18.32							
Aluminium and iron oxides ($Al_2O_3+Fe_2O_3$)..............	3.8	.51	.68	8.38	16.6	3.9	10.5	0.9	2.7	2.7
Calcium (Ca)....................	13.6	11.80	39.52	71.29	61.0	75.3	68.8	7.2	19.0	15.5
Magnesium (Mg)..................	5.5	5.63	14.77	20.59	16.9	21.9	17.0	3.1	6.9	7.6
Sodium and potassium (Na+K)	6.0	3.38	7.82	17.99	23.3	21.6	15.7	5.1	13.4	6.3
Carbonate radicle (CO_3)	39.4	25.70	99.29	96.13	99.6	87.3	129.5	23.3	59.6	45.4
Sulphate radicle (SO_4)..........	1.5	15.90	2.12	109.95	83.0	151.5	46.2	1.5	2.1	4.4
Chlorine (Cl).....................	1.4	.40	5.49	19.38	13.0	14.7	21.0	1.1	1.6	1.4
Organic matter.................	......	10.44	......	......	......	......	......	......	......	......
Total dissolved solids.......	71.	79.	188.	344.	313.	376.	299.	42.	105.	83.

1. Wisconsin River, City Water works, Grand Rapids, Analyst, Chemist, C. M. & St. P. Ry., Nov. 30, 1895.
2. Wisconsin River, Reservoir of City water works, Grand Rapids, Analyst, G. M. Davidson, Mar. 8, 1901.
3. Well of city water works, Marshfield, Analyst, G. M. Davidson, June 11, 1909.
4. Well of C. M. & St. P. Ry. Co., Grand Rapids, Analyst, Chemist, C. M. & St. P. Ry. Co. Oct. 7, 1896.
5. Well of C. M. & St. P. Ry. Co., Grand Rapids, Analyst, Chemist, C. M. & St. P. Ry. Aug. 5, 1892.
6. Well of C. M. & St. P. Ry. Co., Grand Rapids, Analyst, Chemist, C. M. & St. P. Ry., June 5, 1894.
7. Well of C. M. & St. P. Ry. Co, Grand Rapids, Analyst, Chemist, C. M. & St. P. Ry. Co., Nov. 30, 1895.
8. Well of C. M. & St. P. Ry. Co., Babcock, Analyst, Chemist, C. M. & St. P. Ry. Co., Jan. 1, 1892.
9. Well of C. M. & St. P. Ry. Co., Babcock, Analyst, Chemist, C. M. & St. P. Ry. Co., June 7, 1894.
10. Two wells of C. M. & St. P. Ry. Co., Babcock, Analyst, Chemist, C. M. & St. P. Ry. Co., Feb. 6, 1896.

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